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EXPLOSIVE FORMING OF BUTT WELDED PIPE REDUCERS.(U)

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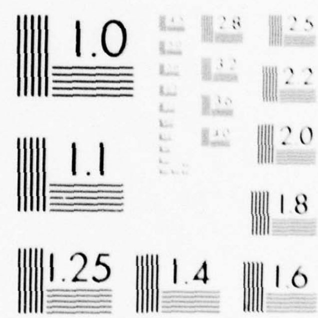

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REPORT NO. MT-052
APRIL 1979

5

EXPLOSIVE FORMING OF BUTT WELDED PIPE REDUCERS

A PROJECT OF THE
MANUFACTURING TECHNOLOGY PROGRAM
NAVAL SEA SYSTEMS COMMAND

FINAL REPORT

NAVAL ORDNANCE STATION
LOUISVILLE, KENTUCKY 40214

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ABSTRACT

This program was conducted to develop a method of explosively forming butt-welded pipe reducers. Forming trials were conducted in both carbon steel and 70-30 copper-nickel material. In addition, a brief formability trial was conducted on copper-nickel-chromium alloy CA 719. Results of burst tests performed on explosively-formed reducers are reported. Data from mechanical testing and metallographic examination of a selected 70-30 copper-nickel reducer are reported. A chart showing the various sizes of reducers that can be formed via this process, and listing the explosive charge size required, is also included. This method offers a cold forging alternative to conventional hot forging methods which require significant amounts of natural gas or other fuels for heating to forging temperatures.

FOREWORD

This is the final report of work completed under NAVSEA Work Requests WR-6-4105 and WR-7-5910 issued to develop explosive forming techniques for the manufacture of butt-welded pipe reducers as used in ship construction. The program was performed by Naval Ordnance Station, Louisville, with funds provided by Naval Sea Systems Command (SEA-0354) Manufacturing Technology Office.

Acknowledgement is given to the following persons whose help with this study is appreciated.

Mr. Robert J. Ferrara	David W. Taylor Naval Ship R & D Center Annapolis Laboratory Annapolis, Maryland 21402
Mr. Dave Carson	Tube Turns Division Chemetron Corp. Louisville, Kentucky 40201

"This Manufacturing Technology report has been reviewed and is approved."

Thad Peake
THAD PEAKE
Director
Manufacturing Technology Department
Naval Ordnance Station
Louisville, Kentucky

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INTRODUCTION

1.1 OBJECTIVES

The objective of this program was to develop a technique for explosively forming the conical shape of butt-welded pipe reducers. Emphasis was placed on both carbon steel and 70/30 copper nickel alloy as used in modern surface ship and submarine construction. The results of this study are intended to:

a. Provide empirically derived explosive forming parameters and techniques for the cold explosive forging of pipe reducers from straight pipe. This information is presented so that any in-house Navy facility or commercial fittings supplier, with sufficient space for an explosive metalworking operation, can duplicate these results.

b. Provide baseline hydrostatic burst test data to establish the basic integrity of an explosively-formed pipe reducer in accordance with accepted piping code practice. This information does not preclude the necessity of additional testing for a specific application, but serves to demonstrate basic comparability with hot-forged reducers.

c. Establish the range of sizes of reducers that can be successfully formed using this process in carbon steel and 70/30 copper nickel alloy.

d. Explore briefly the practicality of utilizing this process on other alloys including copper-nickel-chromium (CA 719).

1.2 BACKGROUND

With the development of modern welding techniques, butt-welded piping components have proliferated in medium and high pressure applications, including ships construction. Butt-welded components are used in numerous shipboard piping systems including power plant and sea water intake systems. Butt-welded reducers are used extensively in these systems to transition from a pipe of one diameter into a pipe of greater or smaller diameter. To minimize turbulence and head loss, reducers are made in the shape of a frustrum, so that flow cross section is gradually changed over a length of approximately one pipe diameter.

The conventional methods of hot-forging pipe reducers are inherently expensive, usually requiring multiple heating and forging operations. In addition, subsequent heat-treating operations are frequently required to restore physical properties. Surface scaling and grain growth are also frequent problems. Explosive forming offers an economical alternative to hot forging techniques, and is particularly suited to the corrosion resistant alloys where grain growth and constituent segregation are potential problems. Another factor to be considered is the behavior of engineering materials used in piping when deformed by impulsive loading. Many materials will exhibit an increase in ductility and formability when subjected to a high strain rate forming operation

such as explosive forming. This increase in ductility allows most materials to be expanded explosively out to their full static values without fracture or springback. In addition, most materials exhibit an increase in yield strength and ultimate strength when formed at high strain rates. However, such changes in material properties are a function of the strain rate, so that no single dynamic value is appropriate for all operations. Material behavior in each case has to be considered in terms of the specific loading function. The results of numerous static and dynamic tensile tests, as well as cylindrical and hemispherical part forming trials have indicated that the elongation characteristics of engineering metals fall into three categories[1]:

a. Materials with high static ductility and a substantially higher dynamic ductility.

(1) 17-7 PH - Semi-austenitic stainless steel

b. Materials with intermediate static ductility and equal to or slightly higher dynamic ductility.

(1) Vascojet 1000 - Martensitic tool steel

(2) USS 12 MoV - Martensitic stainless

(3) Rene 41 - Nickel base super alloy

(4) L-605 - Cobalt base super alloy

(5) A-286 - Austenitic stainless

(6) 2024-0 - Aluminum

c. Materials with low static ductility and equal to or slightly higher dynamic ductility.

(1) 13V-11 Cr-3AL - titanium

(2) 6AL-4V - titanium

Explosive forming is highly applicable to the above Type a materials. Types b and c can also be processed, but with less utilizable ductility.

Explosive forming operations fall into one of two broad categories, standoff and contact shots. In a contact operation, the explosive is placed directly on the workpiece to be formed. Energy is transferred by the shockwave from the explosion directly to the workpiece. In standoff operations (as this report addresses), energy from the explosive is transferred to an intervening medium such as air or water, and is then transferred by the medium to the workpiece. The distance between explosive and workpiece is a primary variable which influences the entire operation.

1

Bruno, E. J., (Ed.), "High Velocity Forming of Metals," Revised Edition, American Society of Tool and Manufacturing Engineers, Dearborn, Michigan, 1968, p. 43.

The interactive nature of the variables in an explosive forming operation is reasonably easy to theoretically define. However, the differences in energy coupling into the workpiece with the generation of stress waves of various intensities can produce widely varied results in the actual behavior of materials. Thus, in most cases, the energy requirements of an explosive forming operation are first estimated by theoretical calculations and then fine tuned by actual forming trials. This is the procedure followed in this project to develop specific parameters for forging pipe reducers.

1.3 TECHNICAL APPROACH

A preliminary study performed by the Manufacturing Technology Department at NAVORDSTALOU indicated that it might be possible to form pipe reducers from cut sections of straight pipe. This work was done on thin-walled pipe (schedule 10) in both carbon and stainless steel. Figure 1 shows a cross-sectional view of the basic forming setup used in this project to extend the technique to heavier walled fittings. The explosive train (detonator, booster, main charge) is centered in a plastic bag filled with water, which is placed inside the pipe to be expanded. The pipe in turn is placed in an external die whose cavity is shaped to the exact configuration required by the reducer. The explosive is contained in an expendable cylinder, made of cardboard, plastic, or glass whose diameter is selected to give the proper standoff distance as well as the proper volume of explosive for the forming shot. The entire setup is then placed on steel blocks which hold the die a slight distance off the deck. This is done to allow venting of the gaseous products of the explosion. The detonator and booster explosive are placed in the top of the main explosive, where initiation takes place. Upon detonation, the explosive at the top of the cylinder creates a radially expanding shock wave which transfers energy through the water to the pipe blank being formed, and acts to pin the blank to the die. As the detonation progresses down the explosive cylinder, the pipe is expanded conically out to the shape of the die cavity. A slight amount of foreshortening occurs as the reducer is formed. However, most metal flow occurs radially as is evidenced by the wall thinning that occurs. After firing, the formed reducer will be tightly formed against the die cavity, requiring moderate force to break the part loose from the die.

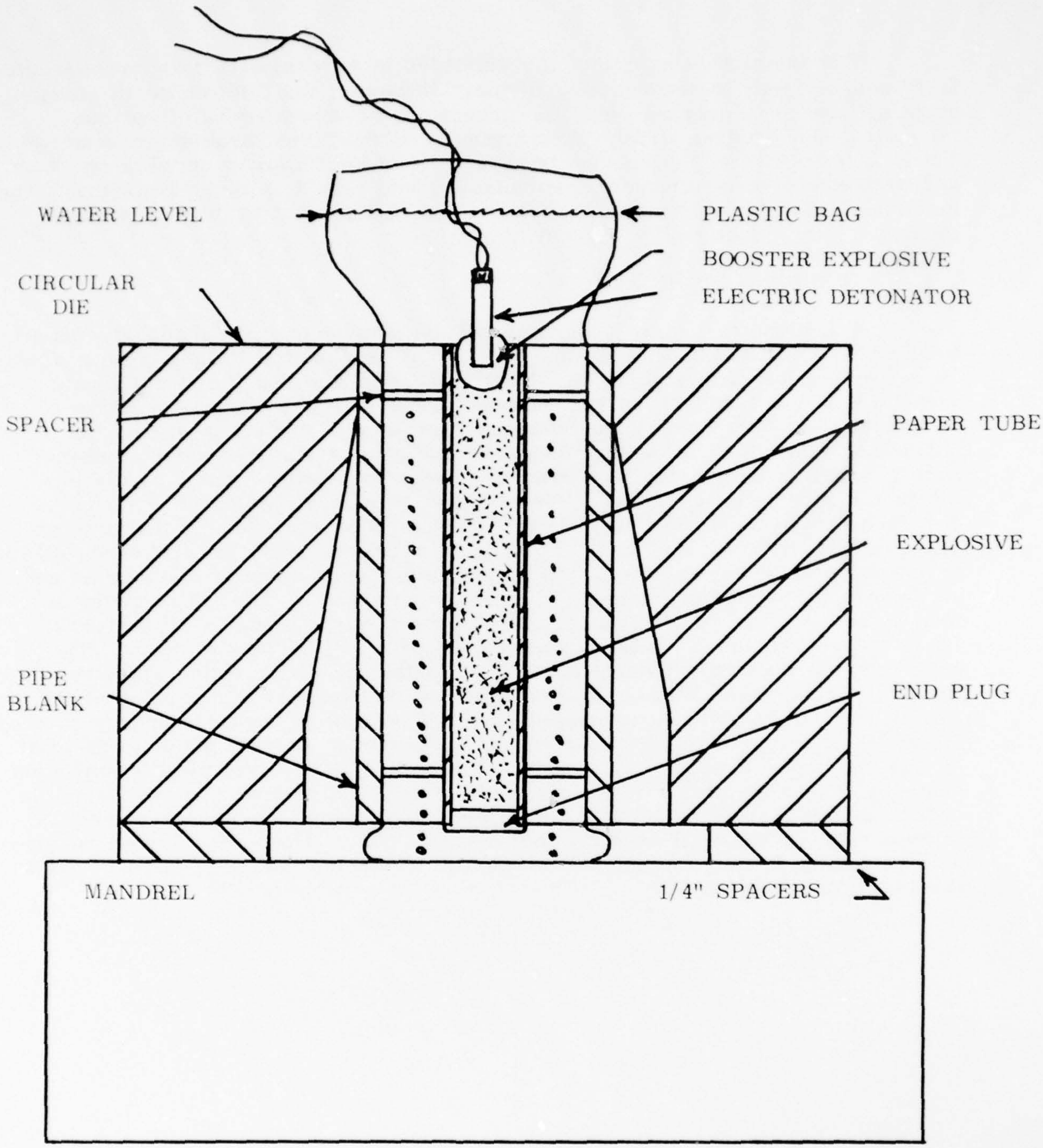

FIGURE 1 CROSS SECTION OF FORGING SETUP

SECTION 2

WORK PERFORMED

2.1 DIE MATERIAL

The selection of a die material for high energy rate forming operations is dependent on many factors including the severity of the forming operation, the number of parts to be formed, the size and thickness of the part to be formed, and the mechanical properties of the metal to be formed. Historically, a number of different materials have been used for HERF dies. A list representative of each of the major categories would include:

a. Mild Steel (AISI 1020)

b. Nodular Cast Iron

c. Medium Carbon Cast Alloy Steel (AISI 8630)

d. High Strength Low Alloy Steel (AISI 4140, 4340)

e. Hardened Tool Steel (AISI 01, A2, S5)

f. Low Melting Alloys (Kirksite, Cerrobend)

g. Epoxy/Fiberglass

h. Concrete

i. Composite Construction

Due to the severity of the forming required to expand a reducer from straight pipe, the die material chosen for this development was AISI 4340 alloy steel. This steel is widely available in various shapes and forms and has a moderate cost due to its relatively low alloy content. However, when quenched and tempered to a hardness of Rc 34 - 36, 4340 has an excellent combination of strength, toughness and fatigue life. For this effort, 4340 steel was purchased in the annealed condition, machined to approximate final dimensions and then heat treated. After heat treatment, the die was machined to final dimensions. Experiments indicated that optimum die dimensional stability, after repeated forming trials, was obtained at higher hardness values. Listed below are properties typical of those observed in the reducer dies:

AISI - SAE 4340

Typical Properties:	Quenched and Tempered
Yield Strength	152,000 psi
Tensile Strength	170,000 psi
Elongation	20%
Reduction of Area	50%

Tensile Modulus	28.5×10^6 psi
Impact Energy, V-notch	48 ft-lb @ 70°F
Endurance Limit, 10^7 cycles	75,000 psi
Hardness	350 Brinell 34 - 36 Rc

Though not pursued in this development, a second choice in die material would be AISI - SAE 1020 mild steel. Because of the low cost and ease of fabricating, mild steel is a good choice for producing small numbers of parts. However, forming operations must be conducted at near room temperature to avoid brittle die behavior. The ductile-brittle transition temperature (DBT) for mild steel in a dynamically stressed mode can be at or above room temperature. Because of the relatively good unnotched fatigue properties of mild steel, it is a good second choice in thin-walled applications requiring moderately severe forming pressure. Listed below are representative properties.

AISI - SAE 1020

ASTM A-285, Grade C

Typical Properties:	Hot Rolled
Yield Strength	32,000 psi
Tensile Strength	60,000 psi
Elongation	34%
Reduction of Area	60%
Tensile Modulus	28.5×10^6 psi
Impact Energy, V-notch	40 ft-lb @ 70°F
Endurance Limit, 10^7 cycles	24,000 psi
Hardness	120 Brinell

2.2 DIE DESIGN

The dies required for the forming of pipe reducers using this process are essentially thick-walled cylinders. The conical configuration of the inside of the die is dictated by the requirements of the formed reducer. Included below is a brief analysis concerned with the determination of the outside diameter of the die to insure that the die behaves elastically. It is to be noted, however, that final die size in this development was based on availability of suitable AISI 4340 steel billets. However, for a production effort, the design considerations below should be considered.

The total energy E_T (inch lb) delivered from a line charge to a tube is treated by Ezra[2] as:

$$E_T = 2\pi C W \left[\sqrt{(1+S/\lambda)^2+(D/2\lambda)^2} - \sqrt{(1-S/\lambda)^2+(D/2\lambda)^2}\right] \qquad \text{Eq (1)}$$

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[2] Ezra, A. A., "Principles and Practice of Explosive Metalworking", Industrial Newspapers Limited, 17/19 John Adam House, Adelphi, London, 1973, p. 42.

Where:

C = explosive constant, in-lb/in^2 (see Table 1, Appendix)
S = half length of workpiece, inches
λ = half length of line charge, inches
W = total weight of explosive charge, pounds
D = inside diameter of workpiece, inches

In the forming of very small parts, the energy delivered by the detonating cap may have a measurable effect but is neglected in this analysis.

Since the workpiece absorbs energy as it expands to the die, not all of the energy E_T is transmitted to the die. For workpiece materials which are strain hardening, the energy absorbed by the workpiece may be calculated as:

$$U_T = \frac{2\pi KS}{n+1}(D_r - h)\,h\left[\ln \frac{D_d}{D_r}\right]^{n+1} \qquad \text{Eq (2)}$$

where K and n are the constants in the stress-strain relationship (See Table 2, Appendix.)

S = half length of workpiece, inches
Dr = outside diameter of workpiece, inches
Dd = inside diameter of the die, inches
h = wall thickness of the die, inches

The energy remaining which must be dissipated and absorbed by the die is then:

$$U_R = E_T - U_T \qquad \text{Eq (3)}$$

In initial forming expansions U_R will be relatively small. In sizing operations, however, U_R can be quite large and must be fully considered.

Consider the design of a die (Figure 2) with given inside radius a and height Hd which must absorb elastically given amounts of energy U_d. Let σ_d be the yield stress of the proposed die material and f be a factor of safety. The die will be designed on the basis of the Tresca yield condition (maximum shearing stress). When subjected to an internal pressure P, the stresses in the radial and tangential direction are:[3]

$$\sigma_r = Pa^2(1 - b^2/r^2)/(b^2 - a^2) \qquad \text{Eq (4)}$$

$$\sigma_\theta = Pa^2(1 + b^2/r^2)/(b^2 - a^2) \qquad \text{Eq (5)}$$

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3 Timoshenko, S. and Goodier, J. N., "Theory of Elasticity", Second Edition, McGraw-Hill, 1951.

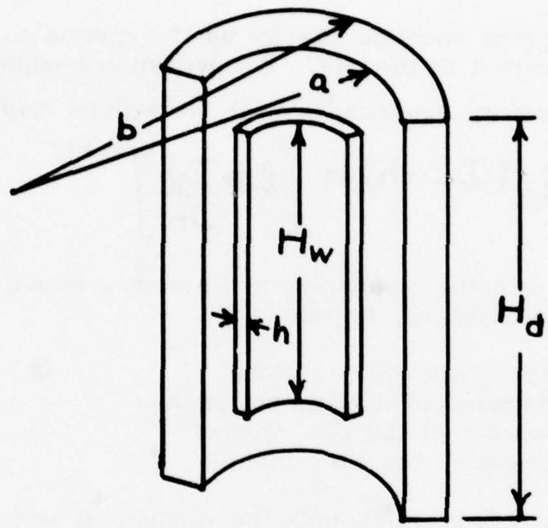

FIGURE 2 DIE DESIGN NOMENCLATURE

The maximum shear stress occurs at the inside of the die (r = a). Using the Tresca yield condition with the factor of safety f gives, for r = a:

$$\tau_{Max} = (\sigma_\theta - \sigma_r)/2 = Pb^2/(b^2-a^2) = \sigma_d/2f \qquad Eq(6)$$

The amount of energy absorbed by the die as the pressure P is applied is:

$$U_d = \tfrac{1}{2} P(2\pi a H_d) u_a \qquad Eq(7)$$

where u_a is the radial displacement of the inside wall of the die under the action of pressure P. The tangential strain ϵ_θ, at any point in the die is $u(r)/r$. This in turn can be related to the stresses σ_r and σ_θ through the appropriate form of Hooke's law. For short cylindrical dies, the appropriate form of Hooke's law is plane stress (no stress in the direction along the axis of the die). The condition of plane stress leads to:

$$u(r) = Pa^2 r\left[(1-\nu)+(1+\nu)(b/r)^2\right] \Big/ \left[E(b^2-a^2)\right] \qquad Eq(8)$$

For long cylindrical dies, the appropriate form of Hooke's law is plane strain (no displacement along the axis of the die) which leads to:

$$u(r) = (1+\nu) Pa^2 r\left[(1-2\nu)+(b/r)^2\right] \Big/ \left[E(b^2-a^2)\right] \qquad Eq(9)$$

where E = Young's modulus for the die material
ν = Poisson's ratio

Equations (8) and (9) can be combined with Equations (6) and (7) to give the energy absorbing capability of each type die. For short dies unrestrained in the axial direction:

$$U_d = \frac{\pi a^2 H_d \sigma_d^2 (1+\nu)(1-a^2/b^2)}{4Ef^2}\left[\frac{(1-\nu)\, a^2/b^2}{(1+\nu)} + 1\right] \qquad Eq(10)$$

where a = inside radius of die, inches
b = outside radius of die, inches
H_d = length of die, inches
σ_d = yield strength of the die material, psi
E = modulus of elasticity of the die material, psi
ν = Poisson's ratio
f = factor of safety

Note, this equation is for the case of short dies like the reducer dies. For the case of long cylindrical dies restrained in the axial direction, the coefficient of (a^2/b^2) becomes $1-2\nu$.

The relationship between U_d and U_R is given for a perfectly elastic collision as:[4]

$$U_d = 4\, U_R\, M_w / M_d \qquad \text{Eq (11)}$$

where Mw = mass of workpiece
Md = mass of die

Equation (11) may be combined with Equation (10) to yield a dimensionless energy ratio which is a function of the radius ratio (b/a). For this case of short dies (plane stress), the resulting equation is:

$$\frac{U_R (\gamma_w/\gamma_d)(H_w/H_d)(D_r\, h/a^2)\, E f^2}{\pi a^2 H_d \sigma_d^2}$$

$$= (1/16)(1+\gamma)(1 - a^2/b^2)^2 \left[(1-\gamma)/(1+\gamma) + b^2/a^2\right] \qquad \text{Eq (12)}$$

where γ_w = specific weight of workpiece, lb/in^3
γ_d = specific weight of die, lb/in^3
D_r = outside diameter of the workpiece, inches
h = workpiece thickness
H_w = height of workpiece, inches
H_d = height of die, inches

For a given workpiece, the energy ratio can readily be calculated for a given die material using the left hand side of Equation (12). With the left hand side known, Equation (12) is found to be a cubic equation for the ratio $(b/a)^2$. Since cubic equations are not readily solved by hand, a graphic or computer aided solution is suggested giving a value for the radius ratio (b/a) for each value of the energy ratio (left hand side of Equation (12)).

2.2.1 Die Backup and Restraint

When forming parts with the wall thickness to diameter ratios common to pipe reducers, Equation (12) can yield (b/a) ratios well in excess of 2.5 (i.e., the outside radius of the explosive forming die will be greater than twice the inside radius). For long term production runs, die billets of this diameter would be practical. However, for this development, economics dictated that die costs be minimized. To accomplish this, a reducer die made from a reasonably sized and readily obtainable AISI 4340 billet was surrounded or backed up with a high impact resistant epoxy system. The epoxy encapsulant was additionally surrounded by a thin cylinder of mild steel. To assemble, the alloy steel billet was centered in the thin wall steel cylinder. The epoxy encapsulant was then mixed and poured in the annular space between the die and the outer cylinder. Figure 3 shows a reducer die encapsulated in epoxy backup. On the smaller size reducer shots, this setup performed well over repeated firings. However,

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[4] See Appendix for development of Equation (11).

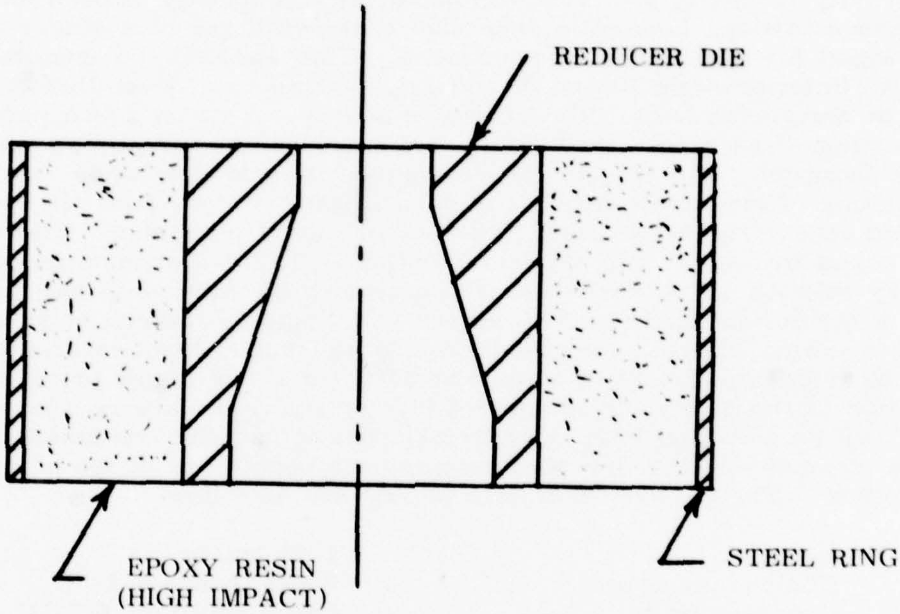

FIGURE 3 CROSS SECTION OF CIRCULAR REDUCER DIE SHOWING EPOXY RESIN BACKUP

on the larger size reducers where explosive charge size exceeded 400 grams, the epoxy backing would only sustain a small number of shots.

2.3 SLURRY EXPLOSIVE

A wide range of high explosives has been utilized in the past to perform explosive forming operations. These have included TNT (trinitrotoluene), PETN (pentaerythritoltetranitrate), RDX (cyclotrimethylene-trinitramine), amonium nitrate, detasheet, Pentolite, Composition C-3 (77% RDX), Composition C-4 (91% RDX), and numerous grades of dynamite. Each of these explosives has characteristic advantages and disadvantages in terms of energy produced and sensitivity to initiation. The Manufacturing Technology Department at Naval Ordnance Station, Louisville, has also made wide use of a slurry explosive developed for use in mining operations. This explosive is manufactured by IRECO (Intermountain Research and Engineering Co., West Jordan, Utah 84084), and is designated DBA-10HV Explosive Slurry. This is a two part explosive consisting of an oxidizer solution, and an aluminum sensitizing powder. Though very flammable, the oxidizer is very insensitive to detonation, and consists of a solution of ammonium nitrate, sodium nitrate, water, and other proprietary ingredients. The sensitizer powder is primarily aluminum. The two components are mixed by weight 75% oxidizer solution with 25% aluminum powder. This slurry solution when mixed has a consistency of thick soup and pours easily into a cylindrical cavity. The slurry will begin to thicken about five minutes after mixing. The oxidizer solution will salt out at temperatures below 20°C and must be prewarmed or stored at 30°C for a few hours prior to mixing. In addition to the safety advantages of this product, the slurry mix adapts well and may be cast into both cylindrical, conical and flat containers. If some of the aluminum remains dry after mixing, the sensitivity of the slurry is slightly increased. The properties of this slurry are as follows:

Density	1.25 gm/cc
Critical Diameter	0.625 inches @ 20°C
Cap Sensitivity	Cap Sensitivity @ 20°C Not Cap Sensitive @ 5°C
Detonation Velocity	3380 m/sec
Calculated Detonation Pressure	35.7 kilobars

Detonation was initiated with an Atlas Engineering electric detonator. A few grams of detasheet were wrapped around the lower end of the detonator to act as a booster. The end of the detonator and booster were inserted into the slurry explosive and taped in place prior to initiation.

2.4 SUBSTITUTING WAX FOR WATER

Historically, the most widely used medium for transferring energy from the explosive to the part being formed has been water. In recent years, explosive experimenters at Denver Research Institute, University of Denver, have substituted paraffin wax for water in explosive autofrettage shots designed to prestress a 5 inch Naval gun barrel. It was felt that the paraffin wax might also perform well in a forming mode applied to pipe reducers. The wax was substituted for water in this development, and proved very efficient as an energy transfer medium. It is felt that the wax is transformed rapidly into

a liquid as it transfers energy to the part being formed, and stays in place somewhat longer than water. Experiments have shown that the wax is 10 - 20% more efficient than water in a cylindrical cavity.

An unexpected advantage of paraffin wax over water is that a thin layer of wax adheres to the internal surface of the reducer and serves to protect the metal from explosive pitting as forming occurs. A marked improvement in the "as formed" finish of the internal surface of the reducers was observed.

The paraffin wax also proved easy to work with in setting up shots. With water as the transfer medium, a plastic bag (or some other mode of containment) has to be utilized to hold the liquid in place. In addition, a container of the proper volume and diameter must be incorporated in the setup to hold the explosive charge. This container must be made of a non-metallic, expendable material such as glass or waterproof cardboard. A metallic container cannot be used due to shrapnel effects.

With wax, the setup is much simpler. The plastic bag is eliminated, in that the wax is cast directly into the pipe blank. A dowel rod of the proper size is centered in the setup and cast in place. The rod is removed after the wax solidifies, forming a cylindrical cavity. A cardboard or plastic disc is fastened to the bottom of the cavity, and the explosive slurry is poured directly into the cavity. No explosive container is required. Figure 4 is a cross-sectional view of a forming setup using paraffin wax.

2.4.1 Explosive Cavity Shape

The use of paraffin wax allowed another important variable to be evaluated. Specifically, the shape of the explosive cavity could be varied from a simple cylindrical shape into a more efficient shape. Figure 5 shows the two alternate shapes evaluated. Shape 1 consists of two cylindrical sections. Shape 2 consisted of a short cylindrical top section joined to a conically tapered section. In both shapes, the upper section was decreased in diameter, creating an explosive cavity of smaller volume at the top of the die, where very little forming takes place. All that is really required at the small end of the forming setup is sufficient explosive to pin the blank to the die as detonation initiates. For a given charge size, this allows more explosive to be positioned lower in the die where the majority of the explosive energy is required. Shape 1 proved more effective in terms of forming, and allowed a 5 - 10% reduction in charge size. For production forming, this would be a significant savings and would justify fabricating this type cavity form for all size parts being formed. However, for this development, the majority of the reducers were formed with a cylindrical explosive cavity.

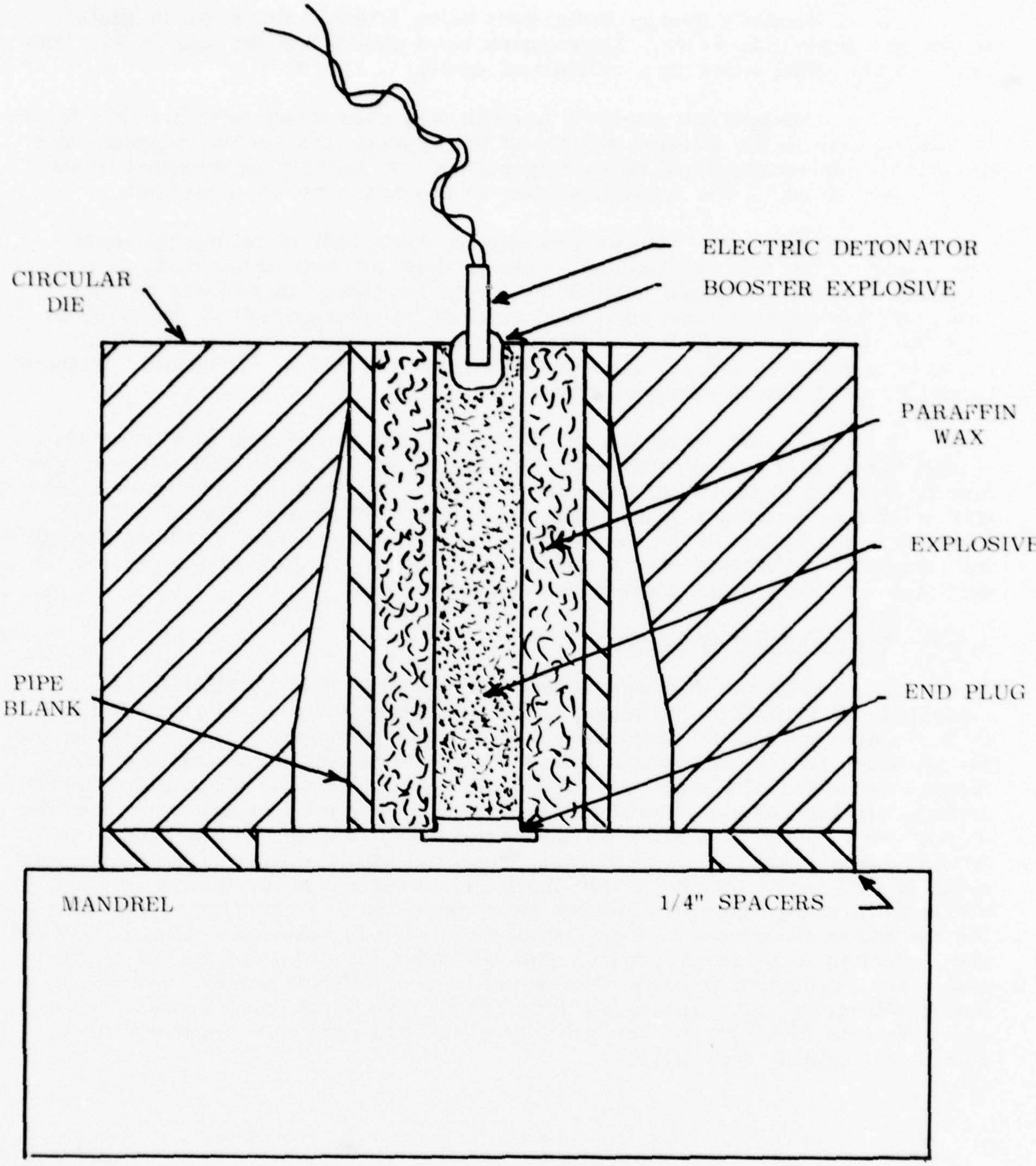

FIGURE 4 CROSS SECTION OF SETUP WITH PARAFFIN WAX

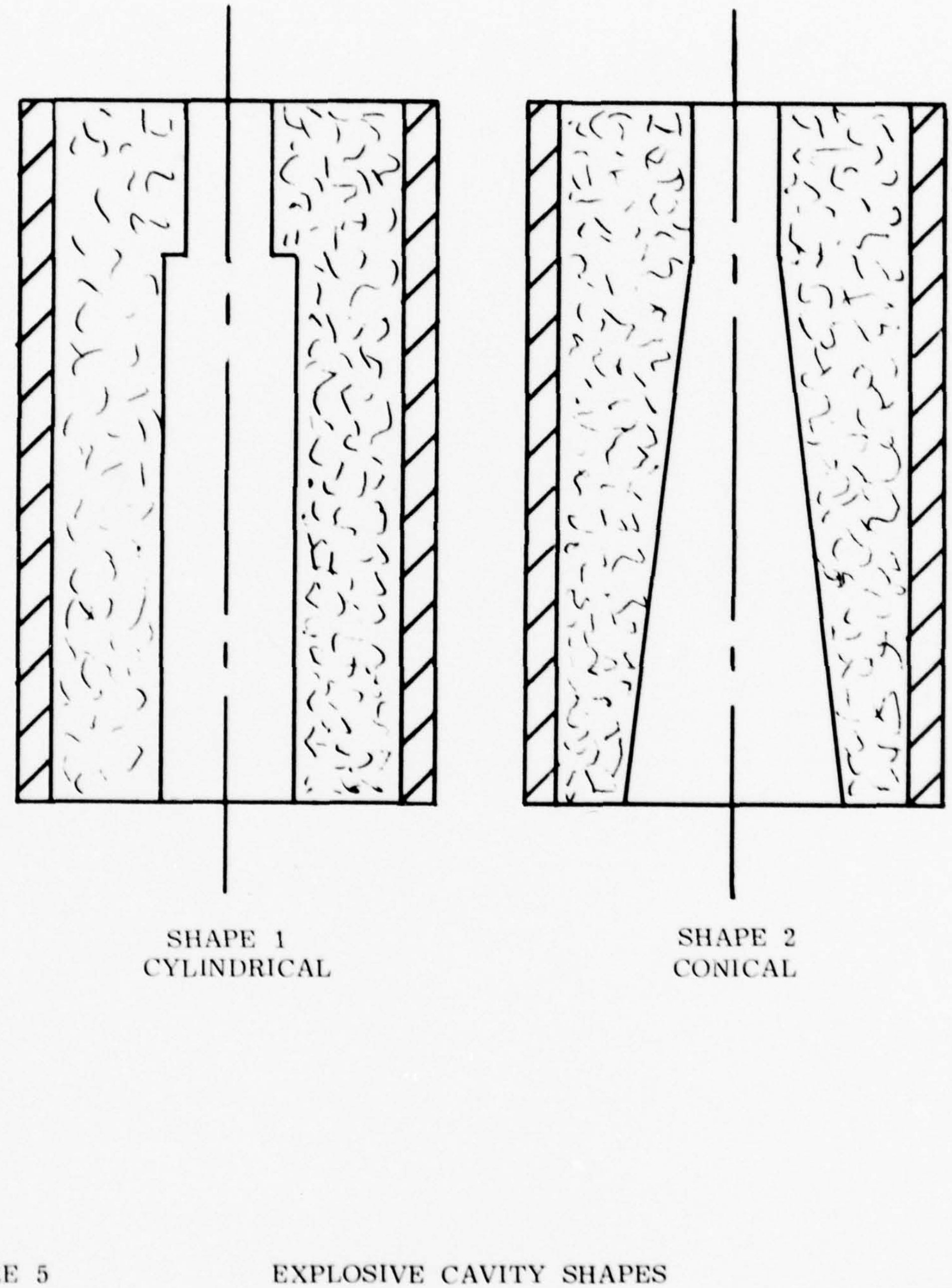

FIGURE 5 EXPLOSIVE CAVITY SHAPES

SECTION 3

RESULTS AND TESTING

3.1 CARBON STEEL DEVELOPMENT

To form carbon steel reducers, a starting pipe material conforming to ASTM Standard A-106-Grade B was utilized. Pipe conforming to this specification is a permissible raw material for the manufacture of factory-made butt-welding fittings conforming to ASTM A-234-WPB. No effort was made to purchase material with specific properties other than the nominal requirements of ASTM A-106-Grade B. The chemical and physical property requirements of this material are listed below.

Chemical Requirements - ASTM A-106-Grade B

Carbon, Max, Percent	0.30
Manganese, Percent	0.29 to 1.06
Phosphorus, Max, Percent	0.048
Sulfur, Max, Percent	0.058
Silicon, Min, Percent	0.10

Tensile Requirements - ASTM A-106-Grade B

Tensile Strength, Min, PSI	60,000	
Yield Point, Min, PSI	35,000	
Elongation in 2 in. Min, Percent	30.00 (Long)	16.5 (Trans)

3.1.1 Carbon Steel Reducer Sizes Producible

Listed below are the sizes of reducers that are producible using the explosive forging process. In almost all cases, a starting pipe wall thickness sufficient to give a standard weight (or Schedule 40) wall thickness at the large end of the reducer after forming was used. This chart was developed from numerous forming trials as well as emperical extrapolation. The finished overall length as well as tangent lengths produced were made in accordance with American National Standard ANSI B16.9-1971 "Factory-Made Wrought Steel Butt-welding Fittings." These sizes represent diametral expansion ratios that are within the cold elongation properties of Grade B. Some additional sizes could be added to this list provided a higher scrap rate could be justified. However, the sizes listed are makable with a low scrap rate.

Nominal Size Designation	Actual Outside Diameters, Inches
1 x 3/4	1.315 x 1.050
1 1/4 x 1	1.660 x 1.315
1 1/2 x 1 1/4	1.900 x 1.660

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2 x 1 1/2	2.375 x 1.900
2 1/2 x 2	2.875 x 2.375
3 x 2 1/2	3.5 x 2.875
3 1/2 x 3	4.0 x 3.5
4 x 3 1/2	4.5 x 4.0
4 x 3	4.5 x 3.5
5 x 4	5.563 x 4.5
6 x 5	6.625 x 5.563
8 x 6	8.625 x 6.625
10 x 8	10.750 x 8.625
12 x 10	12.750 x 10.750
14 x 12	14 x 12.750
14 x 10	14 x 10.750
16 x 14	16.0 x 14.0
16 x 12	16.0 x 12.750

3.1.2 Starting Pipe Wall Thickness

As indicated in the above paragraph, this process utilizes a starting pipe with a wall thickness sufficiently heavy so that as forming occurs, the thinned wall is still adequate for the desired service. After forming, any excess wall thickness at the small end of the reducer can be bored out to the desired inside diameter. Excess wall on the large end can be taper-bored to the proper matching wall. Listed below is the anticipated wall thickness at the large end when a starting pipe thickness corresponding to extra strong wall at the small end is formed.

Nominal Reducer Size	Starting Tube Small Diameter	Thinned Wall Large Diameter	Standard Wall Large Diameter
1 x 3/4	.154	.115	.133
1 1/4 x 1	.179	.133	.140
1 1/2 x 1 1/4	.191	.161	.145
2 x 1 1/2	.200	.153	.154
2 1/2 x 2	.218	.174	.203

3 x 2 1/2	.276	.218	.216
3 1/2 x 3	.300	.256	.226
4 x 3 1/2	.318	.277	.237
4 x 3	.300	.224	.237
5 x 4	.337	.264	.258
6 x 5	.375	.308	.280
8 x 6	.432	.322	.322
10 x 8	.500	.392	.365
12 x 10	.500	.415	.3[illegible]
14 x 12	.500	.452	.375
14 x 10	.500	.376	.375
16 x 14	.500	.433	.375

3.1.3 Starting Pipe Length

Another technique which improved forming was to add additional tangent length to the overall length of the reducer. Early trials indicated that when the pipe blank was cut to give a formed length close to finish length, incomplete forming was observed at the large end. However, when a starting blank a few inches (1 - 3 inches depending upon the reducer size) longer than the finished overall length was used, proper forming was obtained out to any reasonable tangent length. The additional length was added to both the top and bottom of the reducer dies, with the majority going to the large end. The additional length at the top (small end) served to further pin the blank as forming occurs. Figure 6 shows an 8" x 6" reducer with an integral tangent on the large end prior to end detail machining.

3.1.4 Forming Parameters - Carbon Steel

Listed below are the explosive charge weights required to form the various reducer sizes in ASTM A-106-Grade B carbon steel. In addition, the recommended explosive cavity length and diameter to be cast into the wax medium is listed. The explosive cavity length also corresponds to the recommended starting blank length and also the overall die length. The explosive utilized is the DBA 10HV slurry discussed earlier.

Nominal Size	Blank & Explosive Cavity Length, Inches	Explosive Cavity Diameter, Inches	Explosive Charge Weight, Grams
1 x 3/4	3	.5	3" of 200 grain/ft primacord
1 1/4 x 1	3	.6	17
1 1/2 x 1 1/4	3.75	.75	33
2 x 1 1/2	4.5	.841	50
2 1/2 x 2	5.25	.934	72
3 x 2 1/2	5.25	.985	80
3 1/2 x 3	6	.977	90
4 x 3 1/2	6	1.030	100
4 x 3	6	1.128	120
5 x 4	7.5	1.427	240

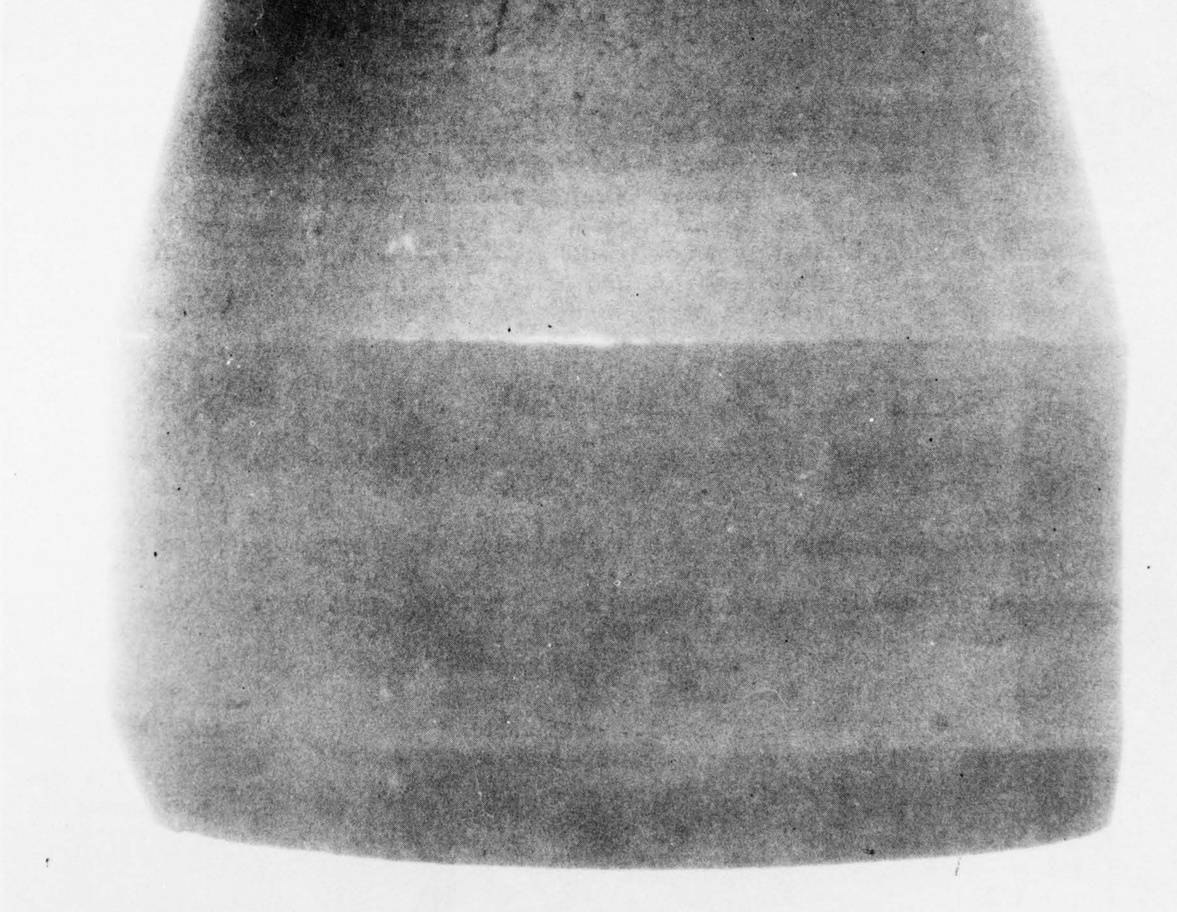


FIGURE 6 PHOTO OF LONG TANGENT ON AS FORMED REDUCER

6 x 5	8.25	1.666	360
8 x 6	9	1.842	480
10 x 8	10	2.173	742
12 x 10	11	2.500	1080
14 x 12	16	2.274	1300
14 x 10	16	2.443	1500
16 x 14	17	2.523	1700
16 x 12	17	2.681	1920

3.1.5 Burst Test per ANSI B16.9 of Carbon Steel Reducer

A widely used measure of performance for wrought steel buttwelding fittings is the hydrostatic burst test as specified by American National Standard (ANSI) B16.9, paragraph 8. To determine the bursting pressure of a fitting, straight pipe of the matching schedule (or nominal wall thickness) and material are welded to each end; each pipe being at least equal in length to twice the outside diameter of the pipe and having proper end closures, applied beyond the minimum length of straight pipe. Hydrostatic pressure is applied until either the computed burst pressure, or an actual failure is achieved. The computed burst pressure is computed by the standard Barlow Formula:

$$P = \frac{2\,St}{D}$$

where:

- P = bursting pressure of pipe, psi
- S = Minimum specified tensile strength of pipe material, psi
- t = Minimum pipe wall thickness, inches. For the purpose of this formula, t is defined as 87 1/2 percent of the nominal thickness of the pipe for which the fitting is recommended for use.
- D = Specified outside diameter of pipe, inches

An 8" x 6" standard weight carbon steel pipe reducer that was representative of the product of this process was burst tested in accordance with ANSI B16.9. The minimum required burst pressure was calculated to be:

for 8"

$$P = \frac{2\,St}{D}$$

$$P = \frac{2(60{,}000)\,(.322)\,(.875)}{8.625}$$

$$P = 3{,}920 \text{ psi}$$

for 6"

$$P = \frac{2(60{,}000)\,(.280)\,(.875)}{6.625}$$

$$P = 4{,}438 \text{ psi (minimum)}$$

The reducer was welded into 8" and 6" pipe legs whose ultimate tensile strength was 72,540 psi and 68,800 psi respectively. The end outside diameters of the reducer measured 8.652" and 6.645" prior to testing. The fitting was hydrotested and a failure was recorded in the 8" pipe at 5,735 psi. The failure occurred as a longtudinal split 13 1/2" long that did not encroach on the reducer. After failure, the end outside diameters of the reducer measured 8.705" and 6.756". Figures 7 - 9 show the test vessel before and after burst testing.

3.2 COPPER NICKEL DEVELOPMENT

After forming setup parameters were established in carbon steel, the technique was extended to include the more costly 70/30 copper nickel alloy. It is with this alloy (as well as other corrosion resistant alloys) that this process would be most attractive. The alloy utilized in this development is designated CA-715 and has the following composition:

CA 715

Composition, percent	70 - 30
Copper (min.)	65.0
Nickel	29.0 - 32.0
Zinc (max.)	1.00
Iron	0.40 - 0.70
Lead (max.)	0.05
Manganese (max.)	1.00
Copper + sum of named elements	99.50
Phosphorous (max.)	.02
Sulfur (max.)	.02

The mechanical properties associated with this material are listed below as stated in Military Specification for Tube MIL-T-16420J (SHIPS).

Mechanical Properties

Composition	Outside Diameter (Inches)	Tensile Strength (Min.) (PSI)	Yield Strength at 0.5 percent Extension Under Load (Min.) (PSI)	Elongation 21 Inches (Min.)
70 - 30	Up to 4 1/2 inclusive	50,000	18,000	35.0
	Over 4 1/2	50,000	15,000	35.0

3.2.1 70/30 Copper-Nickel Reducer Sizes Producible

Listed below are the sizes of reducers that are producible in 70/30 copper nickel using the explosive forging process. Note that a few additional

sizes have been added to the listing derived for carbon steel, even though the elongation of 70/30 copper nickel is the same as carbon steel. This is due to the increase in dynamic ductility that the alloy exhibits at high strain rates. The starting pipe blanks were also given an anneal at 1400°F for one hour prior to forming.

Nominal Size Designation	Actual Outside Diameters, Inches
1 x 3/4	1.315 x 1.050
1 1/4 x 1	1.660 x 1.050
1 1/2 x 1 1/4	1.900 x 1.660
1 1/2 x 1	1.900 x 1.315
2 x 1 1/2	2.375 x 1.900
2 x 1 1/4	2.375 x 1.660
2 1/2 x 2	2.875 x 2.375
3 x 2 1/2	3.5 x 2.875
3 x 2	3.5 x 2.375
3 1/2 x 3	4 x 3.5
3 1/2 x 2 1/2	4 x 2.875
4 x 3 1/2	4.5 x 4
4 x 3	4.5 x 3.5
5 x 4	5.563 x 4.5
5 x 3 1/2	5.563 x 4
6 x 5	6.625 x 5.563
6 x 4	6.625 x 4.5
8 x 6	8.625 x 6.625
10 x 8	10.75 x 8.625
12 x 10	12.75 x 10.75
14 x 12	14 x 12.75
14 x 10	14 x 10.75
16 x 14	16 x 14
16 x 12	16 x 12.75

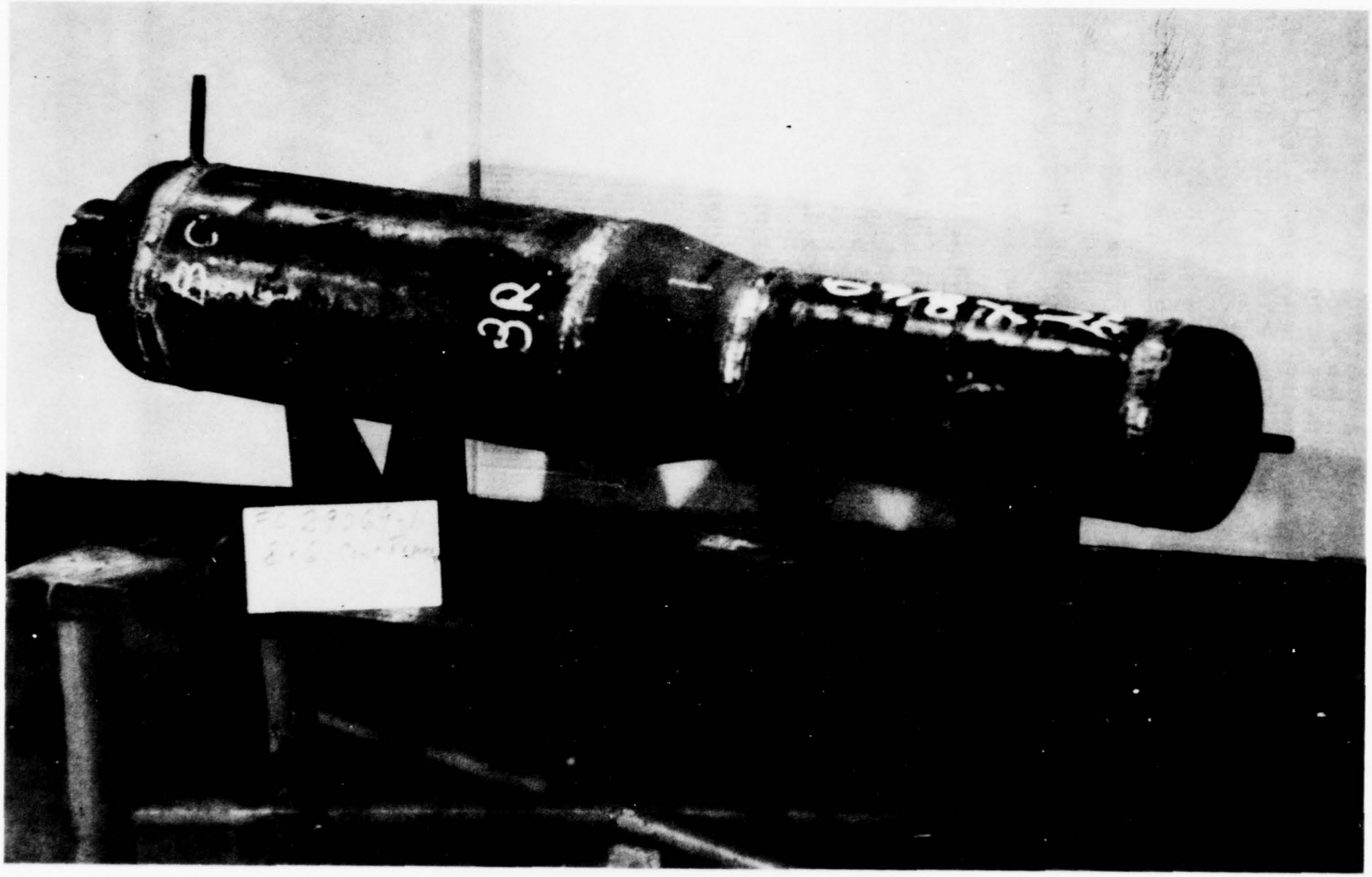


FIGURE 7 PHOTO OF 8 x 6 CARBON STEEL REDUCER WELDED INTO BURST TEST VESSEL

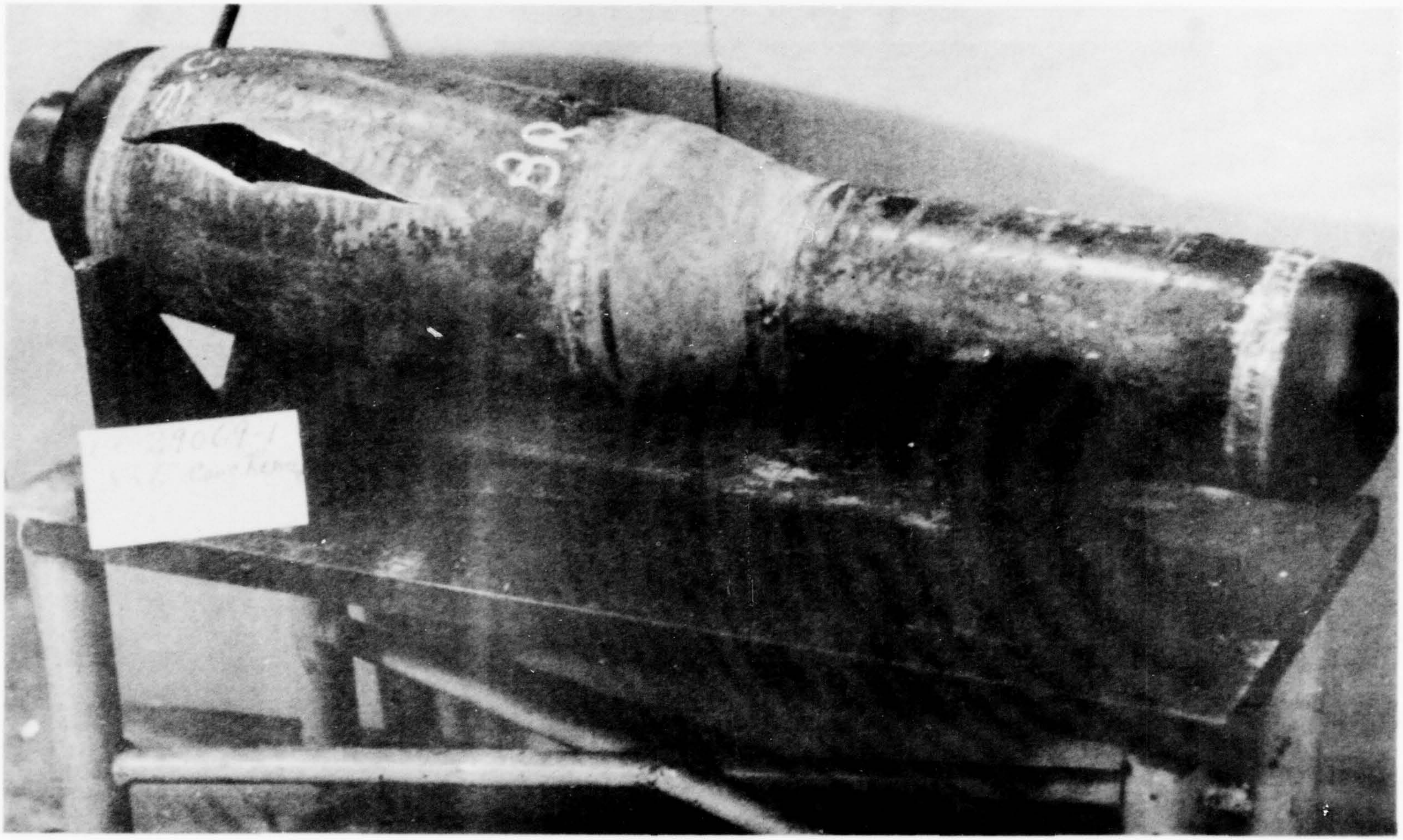


FIGURE 8

PHOTO OF 8 x 6 REDUCER TEST
VESSEL AFTER FAILURE

FIGURE 9 CLOSE-UP PHOTO OF FAILURE (CARBON STEEL)

3.2.2 Starting Pipe Wall Thickness

As with carbon steel, a starting pipe with a wall thickness sufficiently heavy to allow for thinning as a result of forming was used. Excess wall at the small end was bored out to the standard wall inside diameter; excess wall at the large end was 3:1 taper bored. Reference the chart in paragraph 3.1.2 as the thinning observed proved essentially the same for copper-nickel.

3.2.3 Starting Pipe Length

A starting pipe length a few inches longer than the required finish length was utilized. In fact, for comparability, the same starting length as developed for carbon steel was used.

3.2.4 Forming Parameters - 70/30 Copper-Nickel

Listed below are the explosive charge weights and dimensions required to form the various reducer sizes in 70/30 copper-nickel utilizing the DBA 10HV slurry with wax as the energy transfer medium.

Nominal Size	Blank & Explosive Cavity Length, Inches	Explosive Cavity Diameter, Inches	Explosive Charge Weight, Grams
1 x 3/4	3	.5	3" of 200 grain/ft primacord
1 1/4 x 1	3	.6	17
1 1/2 x 1 1/4	3.75	.75	33
1 1/2 x 1	3.75	.75	33
2 x 1 1/2	4.5	.807	46
2 x 1 1/4	4.5	.890	56
2 1/2 x 2	5.25	.895	66
3 x 2 1/2	5.25	.947	74
3 x 2	5.25	.985	80
3 1/2 x 3	6	.938	83
3 1/2 x 2 1/2	6	.977	90
4 x 3 1/2	6	.988	92
4 x 3	6	1.080	110
5 x 4	7.5	1.370	221
5 x 3 1/2	7.5	1.456	250
6 x 5	8.25	1.598	331
6 x 4	8.25	1.757	400
8 x 6	9	1.768	442
10 x 8	10	2.084	682
12 x 10	11	2.398	994
14 x 12	16	2.181	1196
14 x 10	16	2.343	1380
16 x 14	17	2.420	1564
16 x 12	17	2.574	1770

3.2.5 Burst Test per ANSI B16.9 of Copper-Nickel Reducers

Burst tests were conducted on both 8" x 6" standard weight, and 4" x 3" standard weight 70/30 copper-nickel reducers in accordance with ANSI B16.9. Matching pipe legs of carbon steel heat treated to a yield and tensile strength comparable to copper-nickel. The reducers were welded into the legs with a TIG root pass made with 3/32" nickel rod. The balance of welding was SMAW using 1/8 and 5/32 rods of Monel 190. The 8 inch end of the 8 x 6 reducer was slightly oversize and was resized slightly smaller on a reround press before testing. The 8 x 6 reducer sustained a pressure of 6,720 psi before failure occurred as a longitudinal split in the 8" leg. The 4 x 3 reducer sustained a pressure of 9,900 psi before failure occurred as a longitudinal split in the 4" leg. In both cases, failure occurred at a pressure well above that required by ANSI B16.9.

3.2.6 Mechanical Testing and Metallography of 70/30 Copper-Nickel Reducer

To evaluate the effects of the explosive forming process on mechanical properties, an 8 x 6 70/30 copper nickel was sectioned for tensile and impact testing and photographic evaluation. Figure 12 shows the position of the various coupons cut from the reducer. Specimens 1 - 4 were used for sub-scale tensile coupons. Specimens A - F were used for notched charpy impact. However, because of the limiting dimensions of the material, the charpy specimens were undersize thus rendering the charpy values approximate at best.

The four tensile specimens were manufactured per ASTM E-8 and tested at room temperature. Test conditions and results were as follows:

Nominal Gage Section:	.158" dia x .645" long
Head Rate:	.05 in./min.
Strain Rate:	.005 in./in./min.

Specimen Identification	UTS (KSI)	0.2% YS (KSI)	R.A. (%)	Elong. (%)
1	83.2	81.6	76.8	16.7
2	82.3	78.5	73.3	16.9
3	89.1	85.1	73.3	16.3
4	89.1	86.3	72.6	15.7

The six charpy specimens recorded approximate energy values as follows:

Sample Identification	Energy (ft-lbs)
6A	77
6B	59
6C	73
7D	58
7E	68
7F	70

FIGURE 10 8 x 6 COPPER NICKEL REDUCER AFTER BURST TESTING

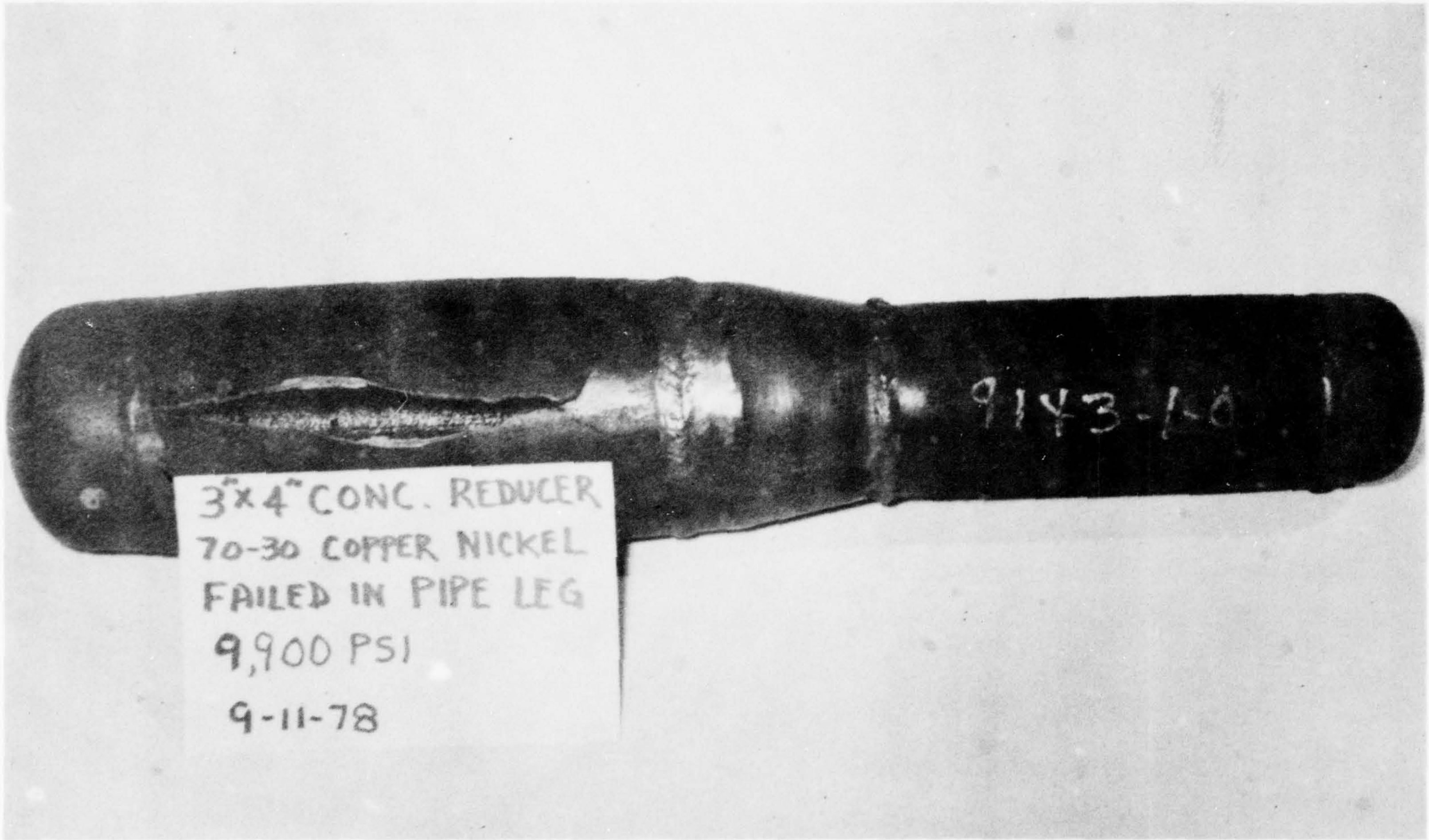


FIGURE 11 4 x 3 COPPER NICKEL REDUCER WELDED INTO BURST TEST VESSEL

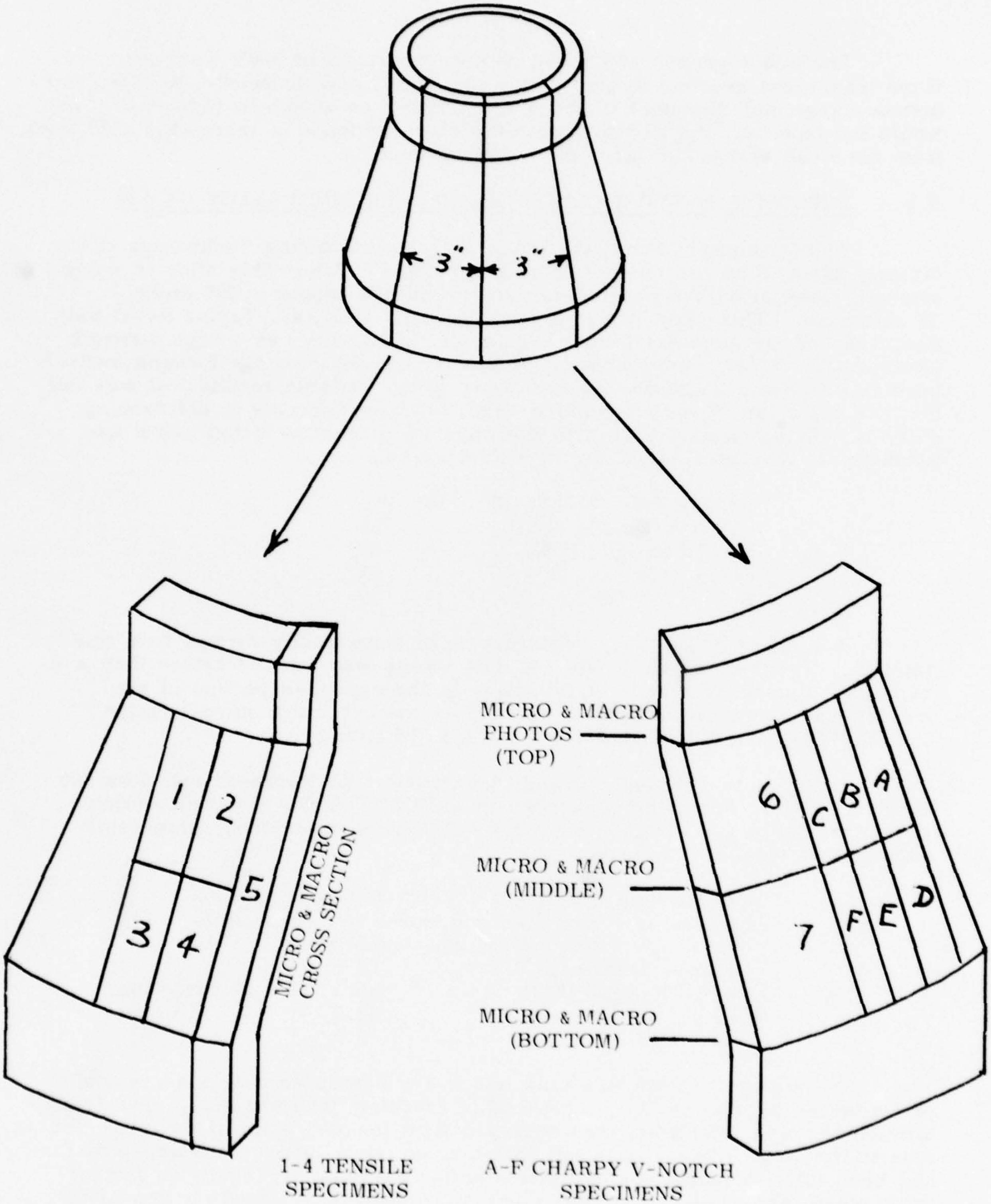


FIGURE 12 SPECIMEN LOCATION ON 8 X 6 COPPER-NICKEL REDUCER

Photomacrographs at 2X and photomicrographs at 100X were taken at three transverse sections located at the top (small end diameter), middle, and bottom (large end diameter) of the 8 x 6 reducer as shown in Figure 12. As would be expected, the microphotographs show evidence of increasing cold work from the small end to the large end of the reducer.

3.3 EXPLOSIVE FORMING COPPER-NICKEL-CHROMIUM ALLOY CA 719

At the request of the NAVSEA (0354) Manufacturing Technology Office, forming trials were run on the alloy designated CA 719. This alloy is a high strength material with a nominal composition of 67% copper - 30% nickel - 3% chromium. This alloy is being considered by David W. Taylor Naval Ship Research and Development Center, Annapolis Laboratory, as a high strength alternative to 70/30 copper-nickel. However, conventional hot forming methods used in producing seamless reducers have given variable results. It was felt that the explosive forming technique might offer an alternate to hot forming methods. A thin-walled tube with the physical properties listed below was furnished to NAVORDSTALOU by NSRDC Annapolis.

CA 719 Tube 2.375" OD x 18" OAL	
Ultimate Tensile (KSI)	95
Yield Strength (KSI)	65
Elong. (%)	28
Red. Area (%)	35

A number of 2 1/2 x 2 reducers were successfully formed from this material. However, since finished 2 inch tubing was utilized rather than a thick-wall pipe blank, the wall thickness in the expanded portion of the reducer was below the minimum required by the applicable specifications (MIL-T-16420J and MIL-F-24202) for a class 700 fitting.

In order to produce a fitting of adequate wall thickness for class 700 service, NSRDC, Annapolis forwarded to NAVORDSTALOU a section removed from an extruded CA 719 pipe having the following dimensions, processing history, and tensile properties.

CA 719 Pipe 3 1/2" OD x 7/16" Wall x 6" OAL	
Processing - Extruded and water quenched while red hot off the runout table.	
Ultimate Tensile (KSI)	66.8
Yield Strength (KSI)	28.3 (at 0.5% extrusion)
Elong. (%)	44.0
Red. Area (%)	61.1

An attempt to form this pipe into a 4 x 3 reducer was unsuccessful as evidenced by Figure 17. Considerable cracking (at some points completely through the wall thickness) was observed from the mid point of the expanded area to the large end. It was felt that further trials using a starting pipe that had been fully annealed might produce better results. However, no further trials were conducted due to unavailability of material. Based on this brief experience, it would appear that CA 719 does not form as readily under high strain rate conditions as 70/30 copper-nickel.

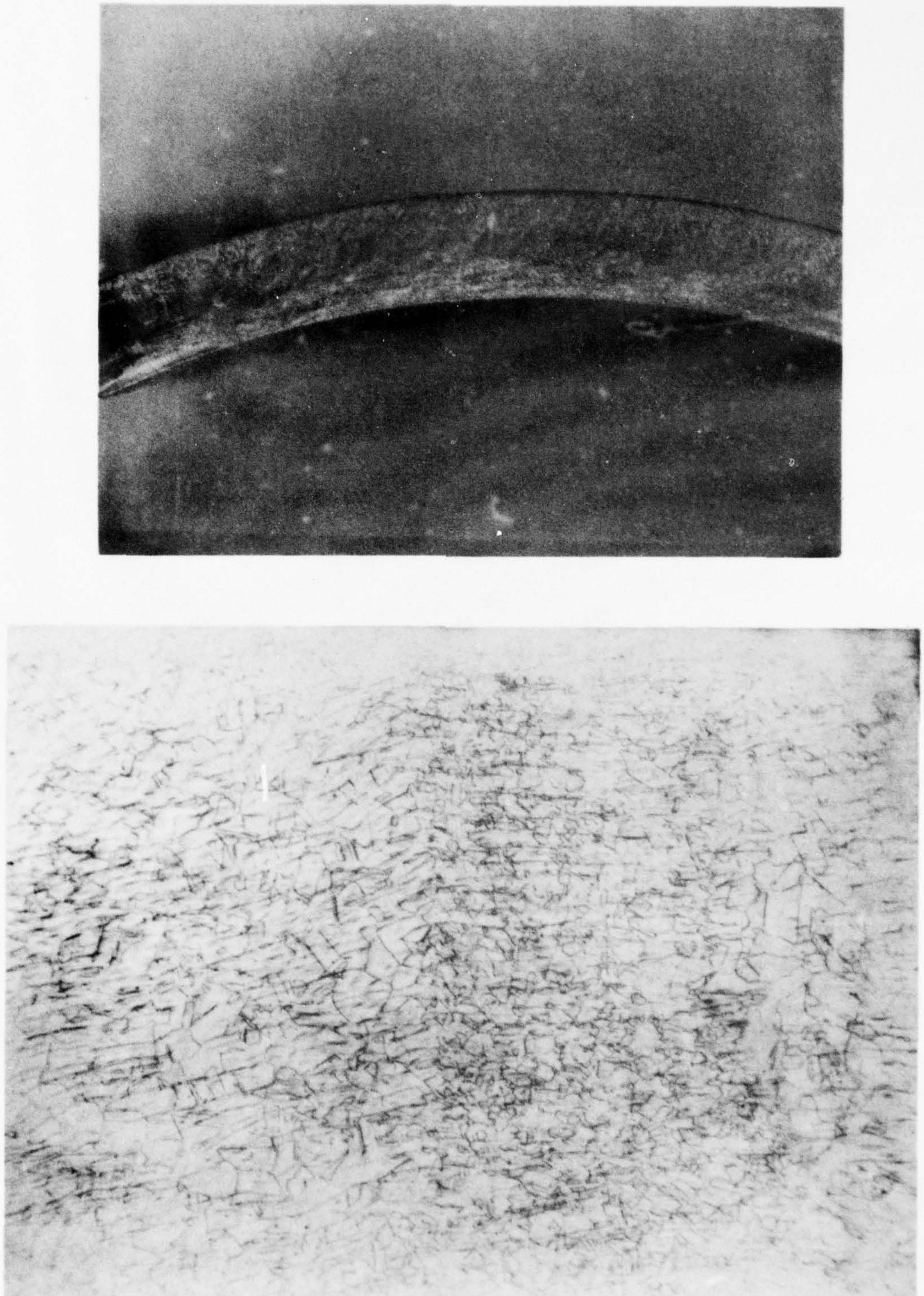


FIGURE 13 MACRO/MICRO PHOTOGRAPHS OF TOP CROSS SECTION OF COPPER-NICKEL REDUCER (2X, 100X)

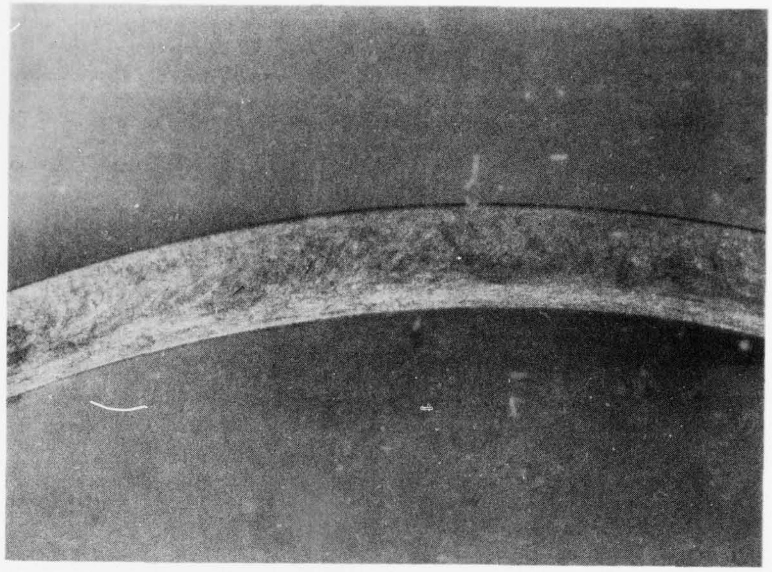
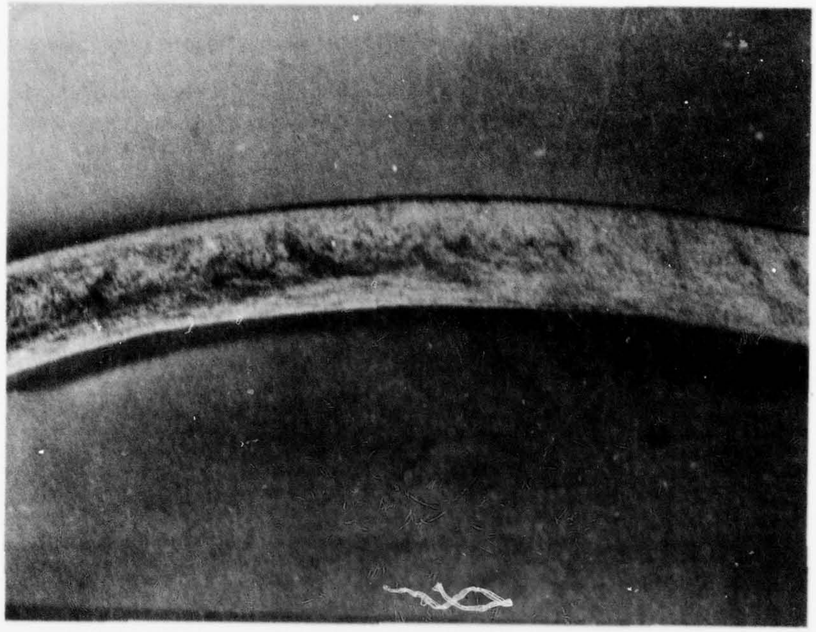


FIGURE 14 MACRO/MICRO PHOTOGRAPHS OF MIDDLE CROSS SECTION OF COPPER-NICKEL REDUCER (2X, 100X)



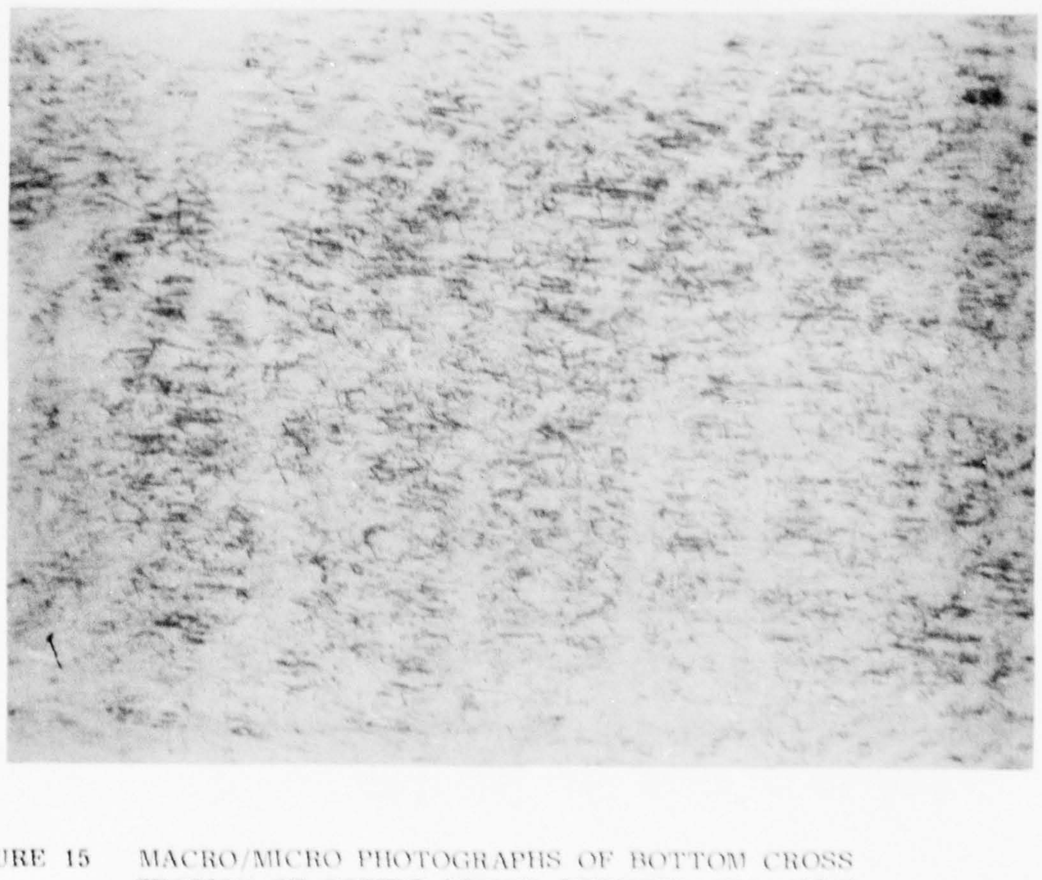


FIGURE 15 MACRO/MICRO PHOTOGRAPHS OF BOTTOM CROSS SECTION OF COPPER-NICKEL REDUCER (2X, 100X)

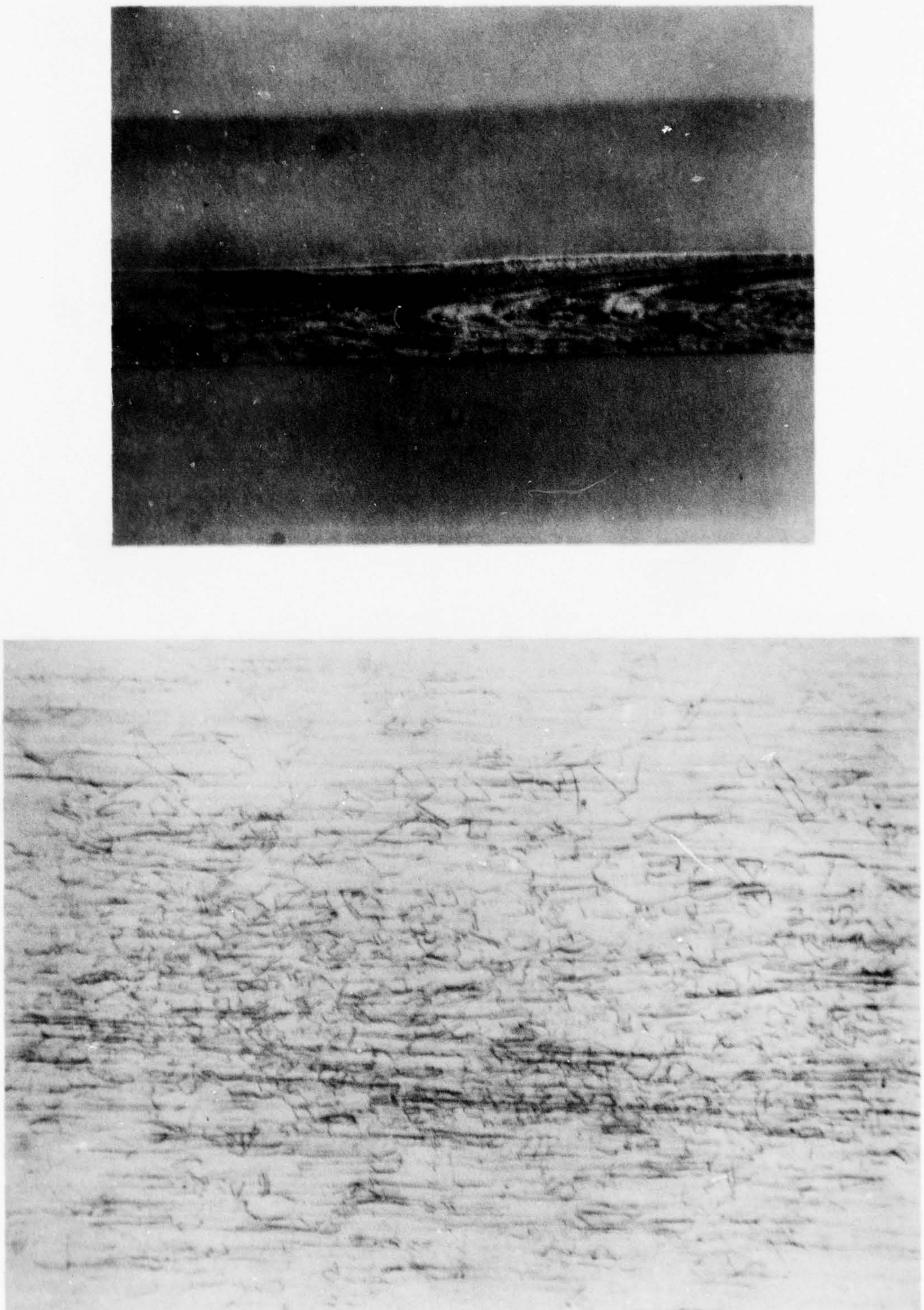


FIGURE 16 MACRO/MICRO PHOTOGRAPH OF LONGITUDINAL SECTION OF COPPER-NICKEL REDUCER (2X, 100X)

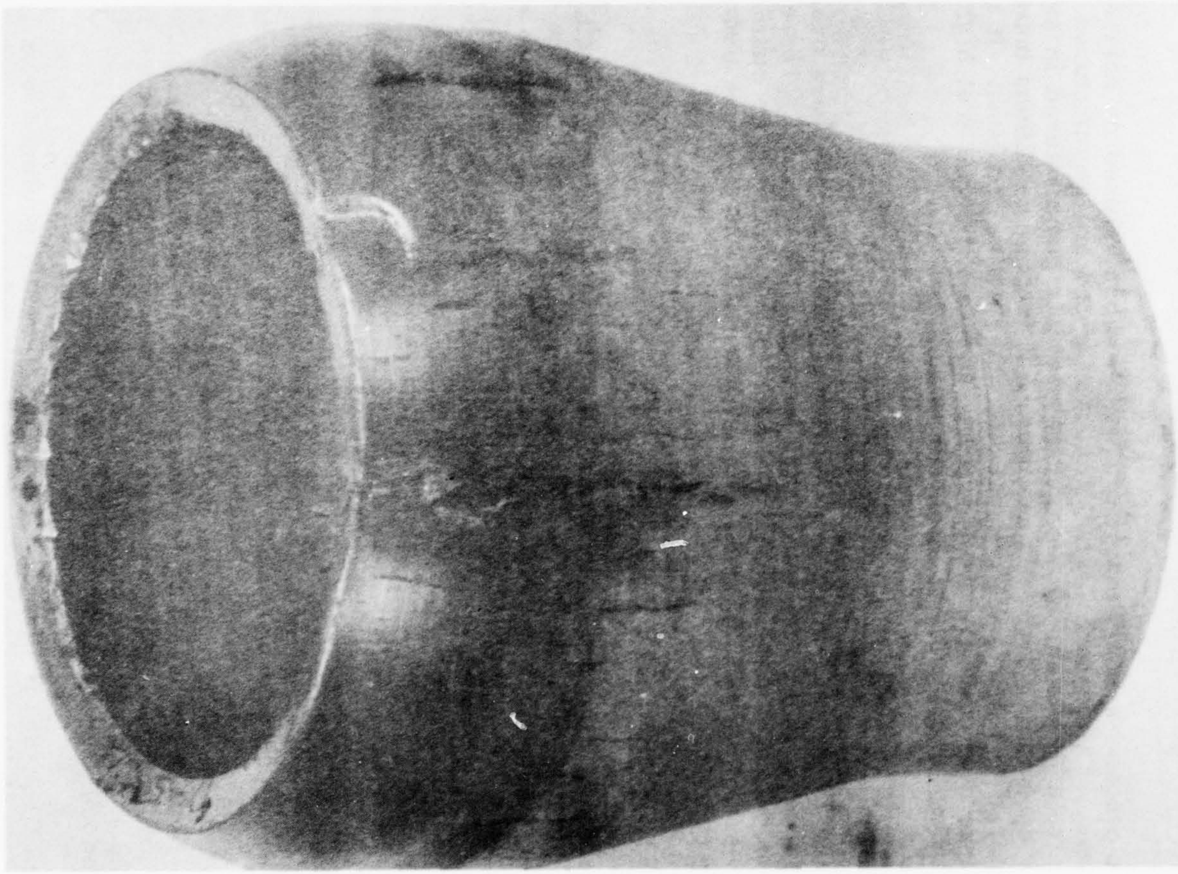


FIGURE 17 CA 719, 4 x 3 REDUCER FORMING TRIAL

SECTION 4

SUMMARY AND CONCLUSIONS

4.1 ECONOMIC PRACTICALITY

This process would be most competitive when utilized on corrosion resistant alloys. Unlike carbon steel reducers which are manufactured in large volumes, corrosion resistant alloy reducers are only manufactured in small quantities as demand requires. In addition, hot forging conditions must be closely monitored to avoid grain growth and other scrap problems. It is in this area where quantities are relatively low and raw material cost high that explosive forming would offer an economic advantage.

4.2 ADDITIONAL MATERIALS FORMED

Figure 18 shows a number of additional materials that were evaluted briefly to determine if forming were feasible using this process. These materials included 6061 and 5083 aluminum, Monel 400, and austenitic stainless steel. It appears that as long as a material has sufficient dynamic ductility, forming is possible.

4.3 ADDITIONAL SHAPES FORMABLE

As shown by Figure 6, this process offers an excellent method of producing long tangent reducers. The process is also well suited for the manufacture of the shallow tapered venturi type reducers. These reducers are used in high flow velocity applications, or where low head loss is required. Eccentric reducers are also formable using this process. A 4 x 3 reducer was successfully formed in both carbon steel and aluminum using an eccentric die and wax with the explosive charge offset away from the straight side.

4.4 RECOMMENDED IMPLEMENTATION

As previously indicated, the major utilization for this technique should be in the area of corrosion resistant alloys commonly used in submarine and surface ship piping. It is recommended that this technique now be implemented by placing explosive formed reducers into service in selected applications aboard Naval vessels. The performance of the reducers could then be periodically monitored in an actual shipboard environment. Based on feedback from this trial utilization, the implementation could be expanded to include all the sizes producible by this process.

Naval Ordnance Station, Louisville is currently equipped with an explosive forming capability that could be utilized to produce reducers now. Numerous other Naval facilities have sufficient real estate, facilities, and trained explosive personnel that could be utilized to produce reducers. In addition, commercial fittings manufacturers could be outfitted for explosive forming with a nominal investment.

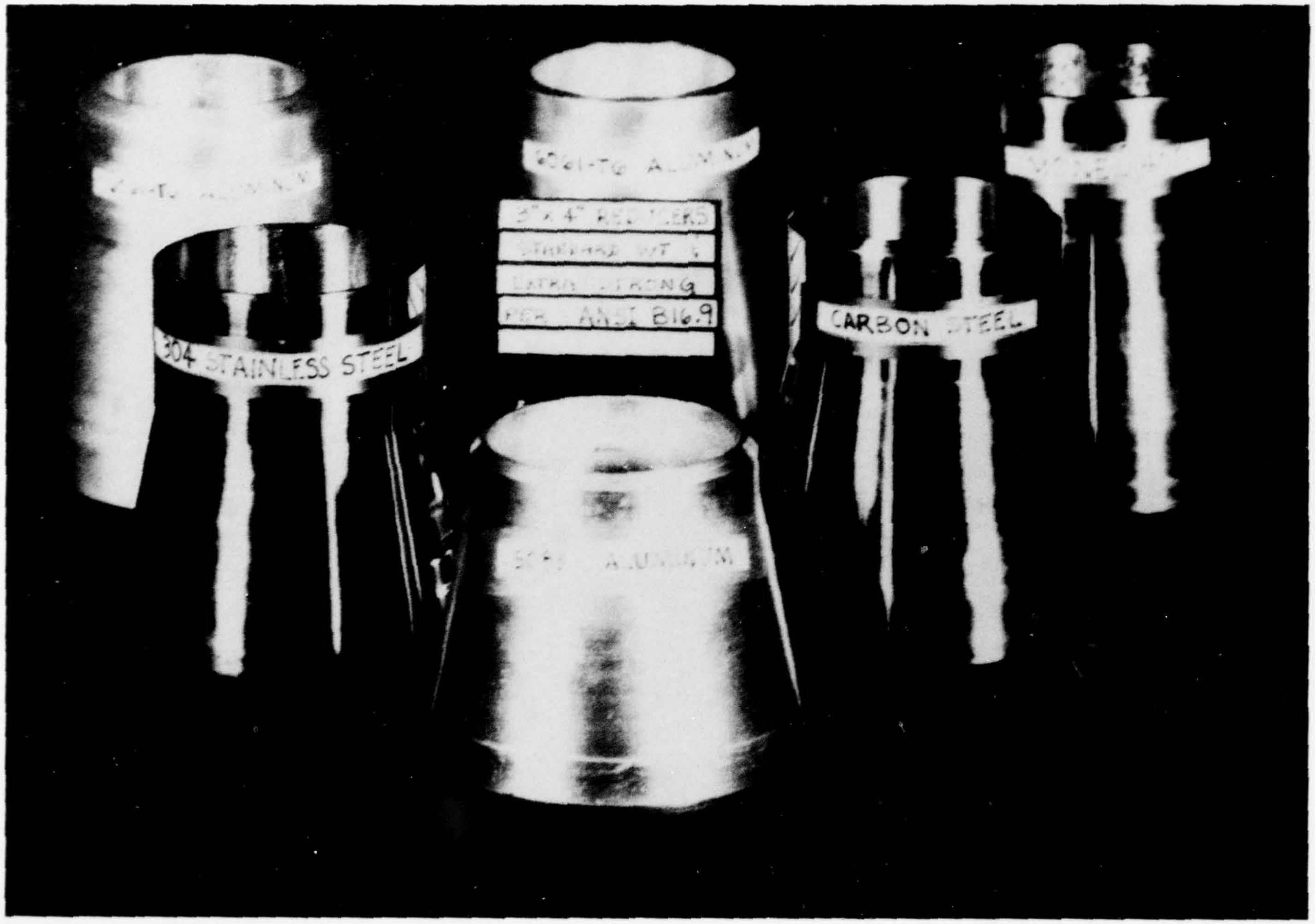


FIGURE 18 ADDITIONAL MATERIALS FORMED: 304 STAINLESS STEEL, 6061-T6 AND 5083 ALUMINUM, AND MONEL 400

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2. PRINCIPLES AND PRACTICE OF EXPLOSIVE METALWORKING, Ezra, A. A., Industrial Newspapers Limited, 17/19 John Adam House, Adelphi, London, 1973.

3. THEORY OF ELASTICITY, Second Edition, Timoshenko, S. and Goodier, J. N., McGraw-Hill, 1951.

APPENDIX

Table 1 - Plastic Strain Hardening Relationships

Table 2 - K and n values

(Development of collision, Ezra, p. 120)

Burst Test Data Sheet 8 x 6 Carbon Steel Reducer

Burst Test Data Sheet 8 x 6 Copper-Nickel Reducer

Burst Test Data Sheet 4 x 3 Copper-Nickel Reducer

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TABLE 1

ENERGY CONSTANTS FOR UNDERWATER EXPLOSIONS

Explosive	$C \times 10^{-3}$
TNT	390
Loose Tetryl	555
Pentolite	640
PETN	520
HBX-1	605
HBX-3	388

TABLE 2

PLASTIC STRAIN HARDENING RELATIONSHIPS

	Material	Strain Hardening Relationship K	n
1.	Aluminum Alloys		
	6061-0	35,000	0.24
	6061-T6	60,000	0.075
	2014-0	46,500	0.244
	2024-0	58,000	0.25
	1100-0	26,000	0.32
2.	Mild Steels		
	1020	76,000	0.12
	0.05% Carbon rimmed-annealed	77,100	0.261
	0.05% Carbon killed-annealed temper Rolled	73,100	0.234
3.	Stainless Steels		
	PH 15-7 Mo	660,000	0.829
	17-7 PH	205,000	0.32
	304 Austenitic	160,000	0.29
		225,000	0.51
	430 (17% Cr Ferrite)	143,000	0.224
4.	High Strength Steels		
	Maraging Steel (18% Ni)	270,000	0.158
	AM 350	770,000	0.87
	4130	120,000	0.35
	A-286	195,000	0.390
	USS 12 MoV	180,000	0.22
	Vascojet 1000	155,000	0.15
	L-605	310,000	0.386
	Ladish D6-AC	387,000	0.073
5.	Refractory Metals		
	Rene-41	315,000	0.39
	Inconel-X	220,000	0.39
	Hastelloy-X	250,000	0.426
6.	Titanium Alloys		
	Ti 6Al-4V	170,000	0.08
	Ti (Beta)	162,000	0.05
	75-A	128,000	0.10
7.	Copper		
	Annealed Copper	75,000	0.38
8.	Brass		
	Brass, Soft	106,000	0.48

COLLISION MECHANICS

(Derivation of Eq. 11)

From the mechanics of two colliding bodies, it is found that the velocity of the die after the collision V_d is related to the velocity of the workpiece before the collision by the formula:

$$V_d = V_w \frac{1+C}{1+\frac{M_d}{M_w}} \approx (1+C)\frac{M_w}{M_d} V_w$$

where C is the coefficient of restitution and (Mw/Md) is the ratio of the mass of the workpiece to the mass of the die. Since the mass of the die is usually much greater than the mass of the workpiece Md/Mw $\gg$ 1, unity has been neglected in comparison to the value of Md/Mw. By recognizing that $U_d = M_d V_d^2/2$ and $U_R = M_w V_w^2/2$, the collision equation becomes:

$$U_d = U_R (1+C)^2 \frac{M_w}{M_d}$$

For a perfectly elastic collision, C is zero; while for a perfectly elastic one in which no energy is lost, C is unity. For a large class of metal to metal collisions, C varies from 0.5 to 0.8. In view of the uncertainties involved, C is taken to be unity.

NOTES

1. "BEFORE TEST," DIAMETERS ARE MEASURED AFTER COMPLETION OF WELDING OF ASSEMBLY.

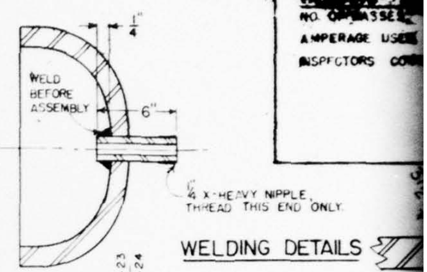
2. ~~DIAMETERS GIVEN IN ( ) ARE MEASURED AT RIGHT ANGLES TO DIAMETERS NOT IN ( )~~

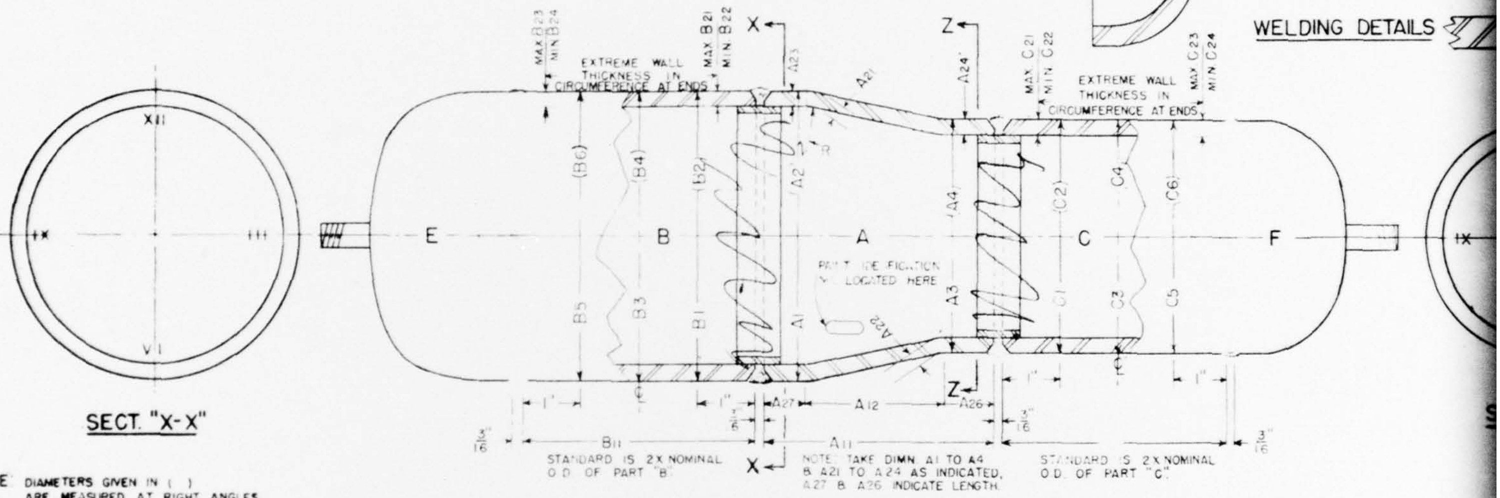
NOTE: DIAMETERS TAKE WITH Pi. TAPE

NO. OF PASSES

AMPERAGE USED

INSPECTORS





NOTE: DIAMETERS GIVEN IN ( ) ARE MEASURED AT RIGHT ANGLES TO DIAMETERS NOT IN ( ).

SPECIMEN NO.	FITTING TYPE	SIZE	SCHED.	MAKE	REF. DRAWING	WEIGHT OF FITTING PROPER: BEFORE GRIND'G	AFTER GRIND'G	NOTES: (SPECIAL FEATURES, HEAT TREATMENT
B2293	CON'C. REDUCER	4" x 3"	40	N.D.S.L.		___ lbs ___ oz	___ lbs ___ oz	

PART	O.D. x NOM. WALL	SPEC & GRADE	MANUF'T'R	LOT	HEAT	U T S (psi)	Y P (psi)	EL in 2 (%)	DIAMETERS (in) 1	2	3	4	5	6	LENGTHS 11	12	13	THICKNESSES 21	22	23	24
A		70/30 CON.				—			4.525 Pi. 4.580 Pi.		NO TANGENT				3 7/8"				.306" N	.275 N	.306 N
B	4.5 x .237	A106 GR B		W6675					4.513 Pi. 4.750 Pi.			4.520" Pi. SPLIT	4.519 Pi. SPLIT		10"			.255	.231	.257	.229
C	3.5 x .216	A106 GR B		W6677					3.513 Pi. 3.588 Pi.			3.517 Pi. 3.623 Pi.	3.519 Pi. 3.575 Pi.		8 1/8"			.231	.212	.227	[illegible]

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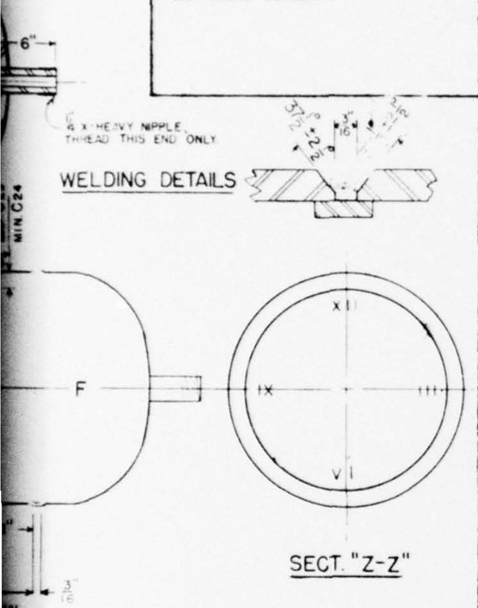
NO. OF PASSES ____
AMPERAGE USED ____
INSPECTORS COMMENTS



TUBE TURNS RESEARCH DEVELOPMENT Louisville, Kentucky

DIMENSIONAL RECORDS AND BURST'G DATA ON CONCENTRIC, REDUCERS SPEC. NO. ____

DATE 8-18-78

№ B2273

TEST NO. ____

FILE NO. ____

REQ'D. MIN. BURST'G PRESSURE PER. ASA B16.9

MIN. SPECIFICATION U T S	S =		psi.
NOMINAL PIPE WALL THICKNESS	t =		in.
SPECIFIED NOMINAL O.D. OF PIPE	D =		in.
REQ'D MIN. BURSTING PRESSURE $\frac{1.75\,St}{D}$	PR =		psi

RECORDED ACTUAL BURSTING PRESSURE: PA = ____ psi

PRESSURE GA. USED:

RATIO OF ACTUAL TO REQ'D. BURST'G PRESS.

P_A / P_R = ____

LOCATION & CHARACTER OF FAILURE:

SEE SKETCH AT LEFT AND PHOTO BELOW.

COMMENTS:

FAILED AT 9900 P.S.I.
LONGITUDINAL SPLIT
IN 4" PIPE LEG

TESTED BY. W. E. CONNER
WITNESSED BY D.C. [illegible]
9-11-78

PRESSURE RECORD CHART

NOTES ON DEFORMATIONS:

COMPUTE % DEFORMATION AT SIGNIFICANT LOCATIONS FROM DIA. "BEFORE" (D_B) AND DIA. "AFTER" TEST (D_A) AS FOLLOWS:

$\% = 100 \times \frac{D_A - D_B}{D_B}$

LOC	A	B	C	D
1				
2				
3				
4				
5				
6				

COMMENTS:

PHOTO OF FAILED SPECIMAN

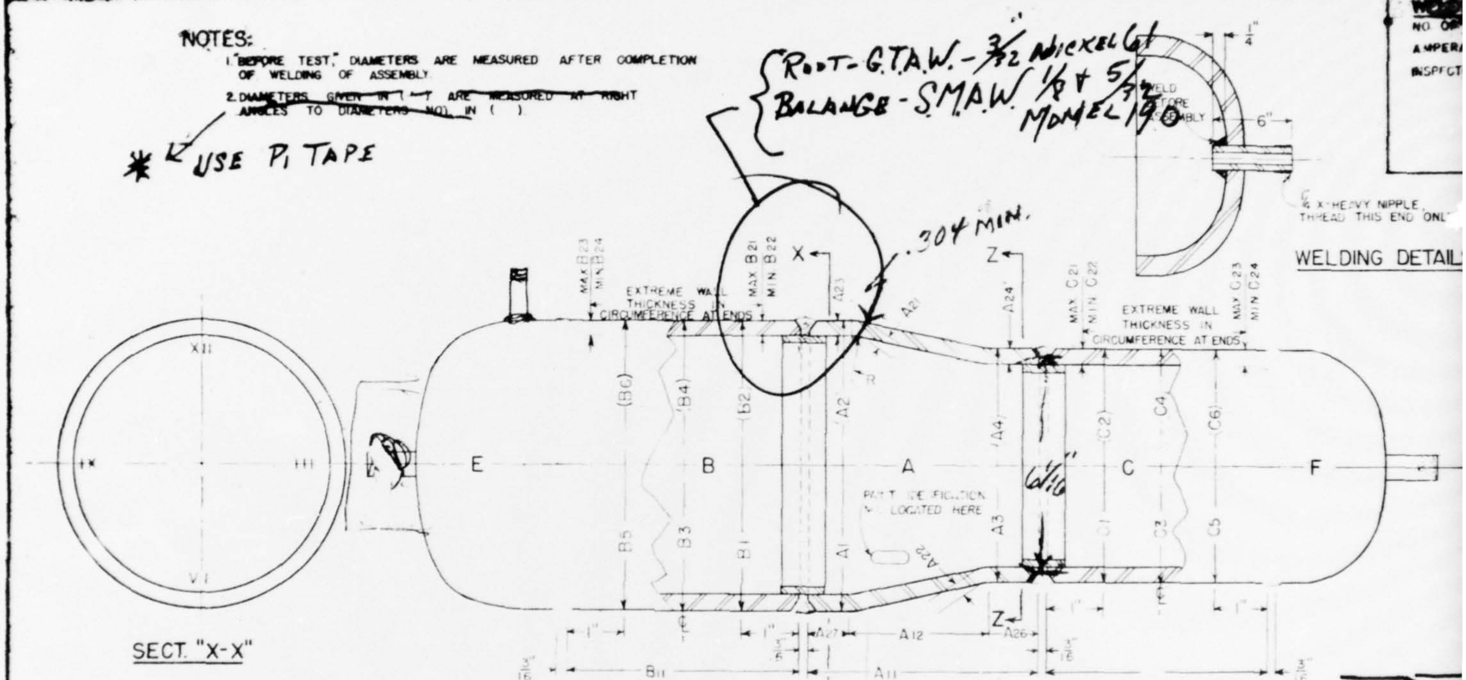
NOTES: (SPECIAL FEATURES, HEAT TREATMENT, ETC.)

	THICKNESSES (in)						
13	21	22	23	24	25	26	27
		306" N	275 N	306" N		0	1 1/4"
	255	231	257	229			
	231	212	227	200			

2

NOTES:
1. "BEFORE TEST" DIAMETERS ARE MEASURED AFTER COMPLETION OF WELDING OF ASSEMBLY.
2. ~~DIAMETERS GIVEN IN ( ) ARE MEASURED AT RIGHT ANGLES TO DIAMETERS NOT IN ( )~~

* USE Pi TAPE



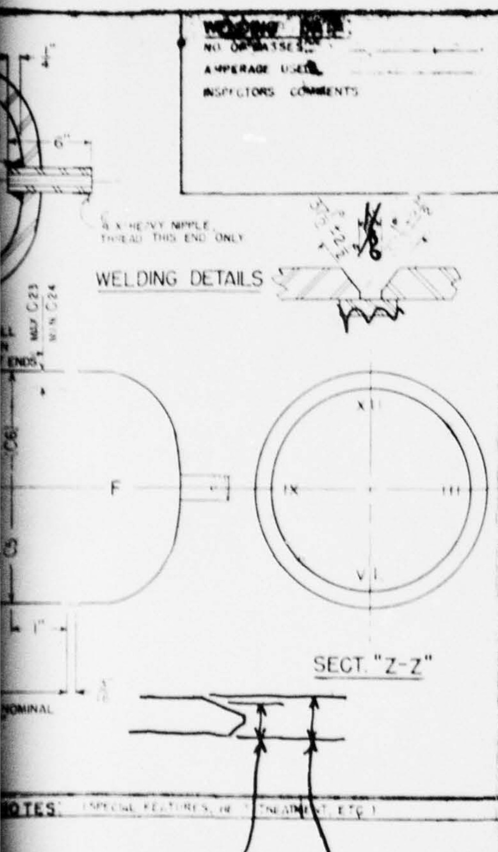
NOTE: DIAMETERS GIVEN IN ( ) ARE MEASURED AT RIGHT ANGLES TO DIAMETERS NOT IN ( ).

BEFORE RESIZE

SPECIMEN NO.	FITTING TYPE	SIZE	SCHED.	MAKE	REF. DRAWING	WEIGHT OF FITTING PROPER: BEFORE GRIND'G	AFTER GRIND'G	NOTES: (SPECIAL FEATURES, HE…
B2287	CONC. REDUCER	8"x6"	40	NOSL		___ lbs ___ oz.	___ lbs ___ oz.	

PART		O.D. x NOMINAL	SPEC & GRADE	MANUF'T'R	LOT	HEAT	UTS (psi)	YP (psi)	EL in 2 (%)	DIAMETERS (in) 1	2	3	4	5	6	LENGTHS 11	12	13	THICK… 21X	22N	23…
FITTING A	BASE METAL									8.906 *		6.648 *									
	BEFORE TEST		70/30 CuNi							8.768 *		6.657 *				5 7/8	3 7/8		391	304	[illegible]
	AFTER TEST									8.871		7.165									
B	BEFORE TEST	8.625x.320	A106 GrB		W B66					8.655 *		8.664 *		8.650 *		17 [illegible]			335 / 344	314 / ~~335~~	33…
	AFTER TEST									split		split		9.013							
C	BEFORE TEST	6.625x.280	A106 GrB		W[illegible]					6.657 *		6.650 *		6.648 *		13 1/4			280	.271	.2…
	AFTER TEST									6.676		6.681		6.665							
	BEFORE TEST																				
	AFTER TEST																				

Q+T.



TUBE TURNS RESEARCH & DEVELOPMENT Louisville, Kentucky

DIMENSIONAL RECORDS AND BURST'G DATA ON CONCENTRIC, REDUCERS

No. 29722 — TEST NO. 82287 — FILE NO.

REQ'D. MIN. BURST'G PRESSURE PER ASA B16.9

MIN. SPECIFICATION U.T.S.	S =	psi.
NOMINAL PIPE WALL THICKNESS	t =	in.
SPECIFIED NOMINAL O.D. OF PIPE	D =	in.
REQ'D MIN. BURSTING PRESSURE $\frac{1.75\,St}{D}$	P_R =	psi.

RECORDED ACTUAL BURSTING PRESSURE: P_A = psi

PRESSURE GA. USED:

RATIO OF ACTUAL TO REQ'D. BURST'G PRESS.
P_A / P_R =

LOCATION & CHARACTER OF FAILURE
SEE SKETCH AT LEFT AND PHOTO BELOW

COMMENTS: FAILED IN "B" LEG AT 6,720 P.S.I. LONGITUDINAL SPLIT $11\frac{3}{4}$" LONG

PRESSURE RECORD CHART

NOTES ON DEFORMATIONS:
COMPUTE % DEFORMATION AT SIGNIFICANT LOCATIONS FROM DIA. "BEFORE" AND DIA. "AFTER" TEST AS FOLLOWS:
% = 100 x $\frac{D_A - D_B}{D_B}$

LOC.	A	B	C	D
1				
2				
3				
4				
5				
6				

COMMENTS:

PHOTO OF FAILED SPECIMAN

NOTES: SPECIAL FEATURES, HEAT TREATMENT, ETC.

12	13	21X	22N	23X	24N	25	26	27
		.391	.304				1"	1"
		.336	.314					
		.314	.325	.331	.313			
		.280	.271	.295	.295			

8

NOTES:
1. "BEFORE TEST," DIAMETERS ARE MEASURED AFTER COMPLETION OF WELDING OF ASSEMBLY.
2. ~~DIAMETERS GIVEN IN ( ) ARE MEASURED AT RIGHT ANGLES TO DIAMETERS NOT IN ( ).~~ USE PI TAPE

π SERVICE ORDER 29069-1

wall thick 87%.7% nom

$P = \frac{2St}{D}$ ACTUAL TENSILE + nom. wall

MIN. CALC BURST 8" pipe leg = 5416 PSI

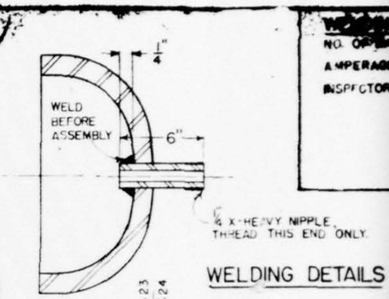
ATCOTRAN 10,000 PSI BOURDON TUBE 1:1 SCALE

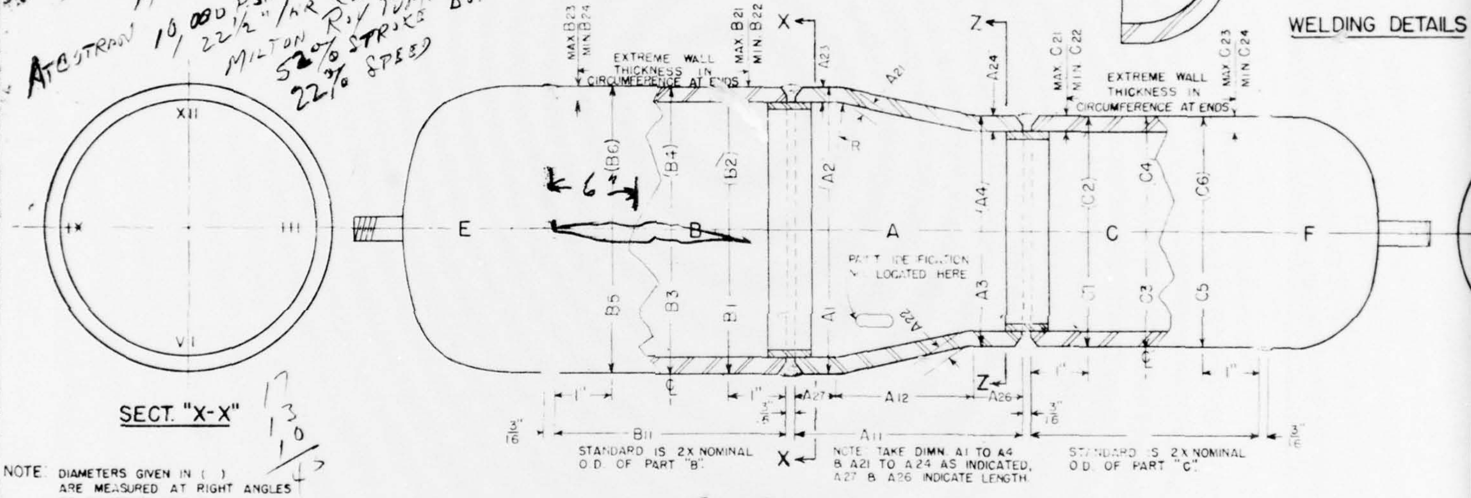
1/22½"/HR CHART SPEED

MILTON ROY PUMP

52% STROKE BOTH PISTONS

22% SPEED





17
13
10
1
41

NOTE: DIAMETERS GIVEN IN ( ) ARE MEASURED AT RIGHT ANGLES TO DIAMETERS NOT IN ( ).

EXPLOSIVE FORMED

SPECIMEN NO.	FITTING TYPE	SIZE	SCHED.	MAKE	REF. DRAWING	WEIGHT OF FITTING PROPER: BEFORE GRIND'G	WEIGHT OF FITTING PROPER: AFTER GRIND'G	NOTES: (SPECIAL FEATURES, HE...)
B2280	CONC. REDUCER	8" x 6"	40	U.S. MAN DRB		___ lbs ___ oz.	___ lbs ___ oz.	

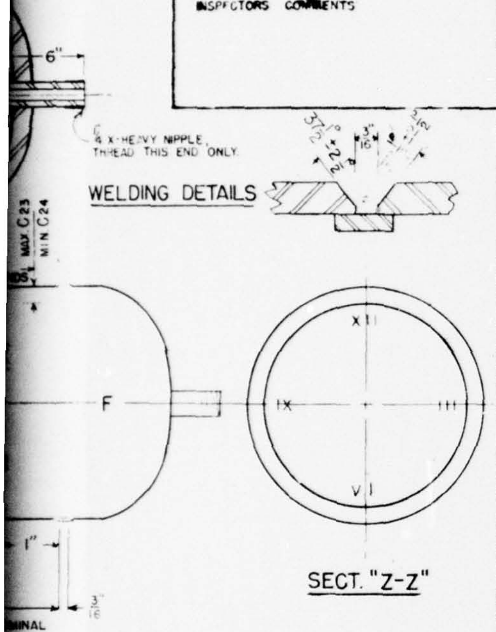
PART		O.D. X NOM. WALL	SPEC & GRADE	MANUFT'R	LOT	HEAT	U T S (psi)	Y P (psi)	EL in 2" (%)	DIAMETERS (in) 1	2	3	4	5	6	LENGTHS 11	12	13	THICKNE... 21	22	23
FITTING	BASE																				
	BEFORE TEST									8.652		6.695									
	AFTER TEST									8.705		6.756									
B	BEFORE TEST	8.625 x 322	A106 GR B		W1511		72,510	48,870	40%	8.652		8.668		8.665		18"					
	AFTER TEST									8.955											
C	BEFORE TEST	6.625 x 280	A106 GR B		W3129		68,800	44,000	39%	6.665		6.672		6.664		14"					
	AFTER TEST									6.809		6.868		6.761							
	BEFORE TEST																				
	AFTER TEST																				

WELDING DATA

NO. OF PASSES: ______

AMPERAGE USED: ______

INSPECTORS COMMENTS



CERTIFIED BY	TUBE TURNS Research & Development, Louisville, Kentucky	No.
INSPECTOR / GEN. INSPECTOR / TEST ENGR.	DIMENSIONAL RECORDS AND BURST'G DATA ON CONCENTRIC, REDUCERS SPEC. NO. ______	TEST NO. ______
DATE 4-26-77		FILE NO. ______

REQ'D. MIN. BURST'G PRESSURE PER. ASA B16.9:

MIN. SPECIFICATION U T S	S =	______	psi.
NOMINAL PIPE WALL THICKNESS	t =	______	in.
SPECIFIED NOMINAL O.D. OF PIPE	D =	______	in.
REQ'D MIN. BURSTING PRESSURE $\frac{1.75\,St}{D}$	P_R =	______	psi.

RECORDED ACTUAL BURSTING PRESSURE: P_A = ______ psi

PRESSURE GA. USED:

RATIO OF ACTUAL TO REQ'D. BURST'G PRESS.

P_A / P_R = ______

LOCATION & CHARACTER OF FAILURE:

SEE SKETCH AT LEFT AND PHOTO BELOW

COMMENTS:

LONGIT SPLIT 13 1/2" LONG IN 8" PIPE LEG AT 5,735 PSI

PRESSURE RECORD CHART

NOTES ON DEFORMATIONS:

COMPUTE % DEFORMATION AT SIGNIFICANT LOCATIONS FROM DIA "BEFORE" AND DIA "AFTER" TEST, AS FOLLOWS:

$\% = 100 \times \frac{D_A - D_B}{D_B}$

LOC	FITTING A	B	PIPE C	D
1				
2				
3				
4				
5				
6				

COMMENTS:

PHOTO OF FAILED SPECIMAN

NOTES: (SPECIAL FEATURES, HEAT TREATMENT, ETC.)

...NS 13	THICKNESSES (in) 21	22	23	24	25	26	27

2

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18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Explosive Forming
Pipe Reducers

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This program was conducted to develop a method of explosively forming butt-welded pipe reducers. Forming trials were conducted in both carbon steel and 70-30 copper-nickel material. A chart showing the various sizes of reducers that can be formed via this process, and listing the explosive charge size required, is included. Results of burst tests performed on explosively-formed reducers are reported.